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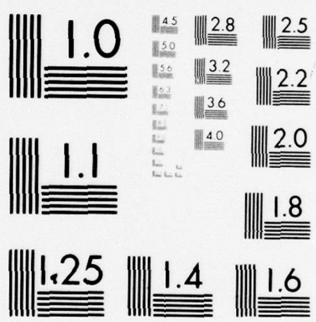

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

WASTE HEAT RECOVERY UNIT DESIGN
FOR GAS TURBINE PROPULSION SYSTEMS

by

Robert Meredith Combs

September 1979

Thesis Advisor: P. F. Pucci

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Waste Heat Recovery Unit Design for Gas Turbine Propulsion Systems

by

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

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ABSTRACT

A design model for a once-through waste heat recovery unit with a segmented fin-tube arrangement was developed along with a simple model of a combined gas and steam (COGAS) turbine propulsion system. These models were integrated and applied in a computer program written in FORTRAN IV for the IBM 360-67 computer. Waste heat recovery unit designs were produced and tested at off-design conditions. Using the space constraints and power requirements of a Navy destroyer-type ship, one design was selected and employed to make estimates of possible fuel savings to be realized through the application of a COGAS system.

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NOMENCLATURE

English Letter Symbols

A - Area (ft^2)

A1 - Estimated Area for Boiling in First Superheater Pass (ft^2)

A_b - Frontal Area Blocked by Tubes and Fins (ft^2)

A_{bt} - Bare Tube Area (ft^2)

A_f - Heat Exchanger Frontal Area (ft^2)

A_{fin} - Fin Area (ft^2)

A_{ff} - Cross-Sectional Area for Fluid Flow (ft^2)

A_i^b - Inside Area Required for Boiling in First Superheater Pass (ft^2)

A_i^{sh} - Inside Area Required for Superheating in First Superheater Pass (ft^2)

A_{ip} - Inside Heat Transfer Area Per Pass (ft^2)

A_{min} - Minimum Cross-Sectional Area for Gas Flow (ft^2)

A_{op} - Outside Heat Transfer Area Per Pass (ft^2)

A_{ti} - Total Heat Exchanger Inside Area (ft^2)

A_{to} - Total Heat Exchanger Outside Area (ft^2)

C - Constant

C_{bhp} - Correction Factor to Gas Turbine BHP for Duct Loss

C_{max} - Maximum Heat Capacity (Btu/hr-F)

C_{min} - Minimum Heat Capacity (Btu/hr-F)

C_{pf} - Specific Heat of Water/Steam (Btu/lbm-F)

C_{pg} - Specific Heat of Gas (Btu/lbm-F)

C_{sfc} - Correction Factor to Gas Turbine BHP for Duct Loss

d_f - Fin Outside Diameter (ft)

d_{fb} - Diameter of Fin Base (ft)

d_i - Inside Tube Diameter (ft)

d_o - Outside Tube Diameter (ft)

d_r - Fin Root Diameter (ft)

f - Friction Factor

G - Gas Flow Rate Per Square Foot (lbm/hr-ft^2)

G_{max} - Maximum Gas Flow Rate Per Square Foot (lbm/hr-ft^2)

h_1 - Enthalpy of Steam at Turbine Inlet (Btu/lbm)

h_2 - Turbine Exhaust Steam Enthalpy (Btu/lbm)

h_{2s} - Turbine Exhaust Steam Enthalpy Assuming Isentropic Expansion (Btu/lbm)

h_f - Enthalpy of Saturated Water (Btu/lbm)

h_{f1} - Enthalpy of Water at Heat Exchanger Inlet (Btu/lbm)

h_{f2} - Enthalpy of Water at Heating Section Outlet (Btu/lbm)

h_{f3} - Enthalpy of Steam at Boiling Section Outlet (Btu/lbm)

h_{f4} - Enthalpy of Steam at Superheater Outlet (Btu/lbm)

h_{fg} - Enthalpy Increment for Boiling (Btu/lbm)

h_{fw} - Enthalpy of Heat Exchanger Feedwater (Btu/lbm)

h_ℓ - Heat Exchanger Inside Heat Transfer Coefficient in Heating or Superheating Section (Btu/hr-ft^2-F)

h_{tpf} - Heat Exchanger Inside Heat Transer Coefficient in the Two-Phase Region (Btu/hr-ft^2-F)

j - Heat Transfer Colburn j-factor

k_g - Thermal Conductivity of Gas (Btu-hr-ft-F)

k_ℓ - Thermal Conductivity of Steam/Water (Btu/hr-ft-F)

k_w	-	Thermal Conductivity of Heat Exchanger Tube Wall (Btu/hr-ft-F)
ℓ	-	Fin Height (ft)
ℓ_c	-	Length of Cut from Fin Tip (ft)
L	-	Tube Length (ft)
$\dot{m}_f$	-	Steam/Water Flow Rate (lbm/hr)
$\dot{m}_g$	-	Gas Flow Rate (lbm/hr)
$\dot{m}_g^b$	-	Gas Flow Rate in Boiling Section of First Superheater Pass (lbm/hr)
$\dot{m}_g^{sh}$	-	Gas Flow Rate in Superheating Section of First Superheater Pass (lbm/hr)
n	-	Number of Passes
N,NTU	-	Number of Transfer Units
N_f	-	Number of Fins Per Inch
N_s	-	Number of Segments in One Fin
$N_{t/r}$	-	Number of Tubes Per Row
P	-	Pressure (psia)
P_1	-	Steam Pressure at Steam Turbine Inlet (psia)
P_f	-	Steam/Water Pressure in Heat Exchanger (psia)
P_{gt}	-	Gas Turbine Horsepower
P_{st}	-	Steam Turbine Horsepower
P_{tot}	-	Total System Horsepower
Q	-	Heat Transfer Rate (Btu/hr)
Q_b	-	Heat Transfer Rate in Boiling Section (Btu/hr)
Q_h	-	Heat Transfer Rate in Heating Section (Btu/hr)
Q_p	-	Heat Transfer in a Heat Exchanger Pass (Btu/hr)
Q_{sh}	-	Heat Transfer Rate in Superheating Section (Btu/hr)

Q_{rb} - Required Heat Transfer Rate in Boiling Section of First Superheater Pass (Btu/hr)

q'' - Heat Flux (Btu/hr-ft^2)

R_{th} - Thermal Resistance (hr-ft^2-F/Btu)

R_o - Heat Exchanger Outside Resistance (hr-ft^2-F/Btu)

s - Entropy (Btu/lbm-F)

s_1 - Entropy of Steam at Turbine Inlet (Btu/lbm-F)

s_f - Entropy of Saturated Water (Btu/lbm-F)

s_{fg} - Entropy Increment for Evaporation (Btu/lbm-F)

S_n - Tube Spacing Normal to Gas Flow (ft)

S_p - Tube Spacing Parallel to Gas Flow (ft)

T_1 - Steam Temperature at Turbine Inlet (F)

T_{fb} - Steam/Water Bulk Temperature (F)

T_{f1} - Water Temperature at Heat Exchanger Inlet (F)

T_{f2} - Water Temperature at Heating Section Outlet (F)

T_{f3} - Steam Temperature at Boiling Section Outlet (F)

T_{f4} - Steam Temperature at Superheating Section Outlet (F)

t_f - Fin Thickness (ft)

T_{g1} - Average Gas Temperature at Heat Exchanger Inlet (F)

T_{g2} - Average Gas Temperature at Boiling Section Inlet (F)

T_{g3} - Average Gas Temperature at Heating Section Inlet (F)

T_{g4} - Average Gas Temperature at Heat Exchanger Outlet (F)

T_{gb} - Gas Bulk Temperature (F)

T_{gf} - Gas Side Film Temperature (F)

$T_{sat\ f}$ - Temperature of Saturated Water (F)

T_{wo} - Average Outside Tube Wall Temperature (F)

U_{oi} - Overall Heat Transfer Coefficient (Btu/hr-ft^2-F)

w_s - Fin Segment Width (ft)

W_t - Steam Turbine Work (Btu/lbm)

W_{ts} - Isentropic Steam Turbine Work (Btu/lbm)

x - Steam Quality

x_a - Average Steam Quality

x_2 - Turbine Exhaust Steam Quality

x_{2s} - Turbine Exhaust Steam Quality Assuming Isentropic Expansion

Dimensionless Groups

N_u - Nusselt Number

P_r - Prandtl Number

R_e - Reynolds Number

S_t - Stanton Number

Greek Letter Symbols

ΔP - Pressure Change (psia)

ΔT - Temperature Change (F)

ε - Effectiveness

ε_b - Effectiveness of Boiling Section of First Superheater Pass

ε_{oa} - Effectiveness Overall for a Heat Exchanger Section

ε_p - Effectiveness for a Heat Exchanger Pass

μ_b - Viscosity at Bulk Temperature (lbm/ft-hr)

μ_w - Viscosity at Tube Wall Temperature (lbm/ft-hr)

η_f - Fin Efficiency

η_{th} - System Thermal Efficiency

η_{st} - Steam Turbine Efficiency

ρ - Density (lbm/ft^3)

ρ_ℓ - Density of Saturated Water (lbm/ft^3)

ρ_v - Density of Saturated Vapor (lbm/ft^3)

I. INTRODUCTION

A. BACKGROUND

The U. S. Navy has made a commitment to gas turbine propulsion systems, with two classes of gas turbine ships entering the fleet (DD-963 and FFG-7) and one class proposed (DDG-47) at the time of this writing. The DD-963 class has two shafts with two General Electric LM 2500 gas turbines powering each shaft. The FFG-7 class is a single-shaft ship with two LM 2500 gas turbines. The DDG-47 class propulsion plant, as proposed, will be similar to that of the DD-963 class.

Currently, means for conserving fuel are being sought in all sectors of the economy and government. In most of our steam turbine-powered ships fuel conservation must be pursued largely through operating practices such as reduced steaming time or reduced speed when steaming. Several alternatives exist, however, for fuel consumption reduction for the gas turbine propulsion system. These alternatives involve combining another type of propulsion system with the gas turbine in order to reduce the overall fuel consumption by either operating the combined systems in parallel or by operating the less expensive system in the cruise mode. Some examples of these combinations are:

Gas Turbine and Diesel (CODOG, GODAG)

Gas Turbine and Steam (COGAS) (steam system not separately fired)

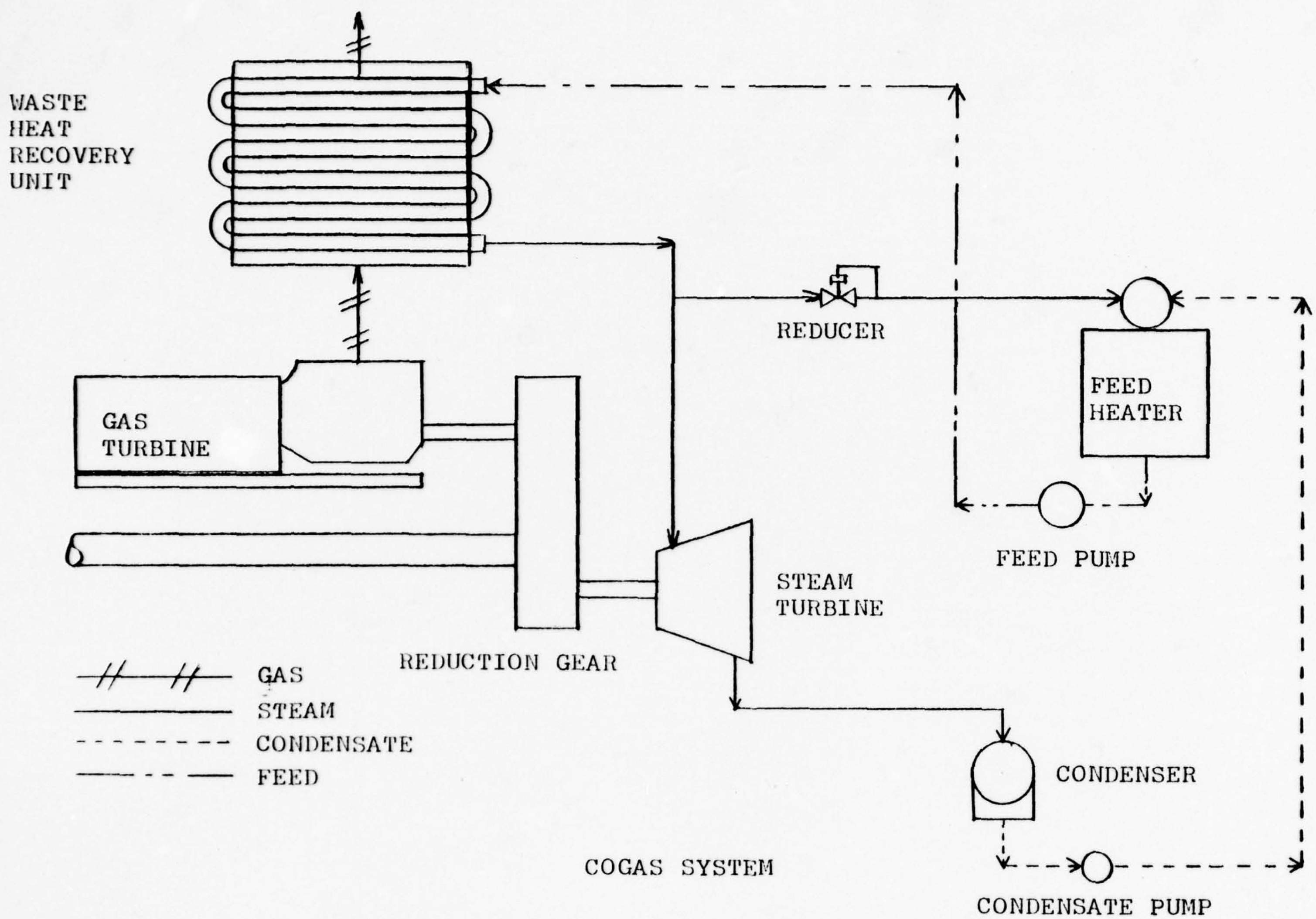
Gas Turbine and Steam (COSAG) (steam system separately fired)

The COmbined Gas turbine And Steam turbine (COGAS) system is probably the best of these alternatives with respect to fuel consumption, initial cost, maintenance, and manning requirements.

The COGAS ship propulsion plant uses the exhaust heat from a gas turbine to generate steam in a waste heat recovery unit (WHRU). This steam is used to drive a steam turbine which is operated in parallel with the gas turbine, for ship propulsion. A common reduction gear connects both turbines to the propeller shaft. Figure 1 illustrates the COGAS system.

Several studies have examined the potential of the COGAS system for improving propulsion plant fuel efficiency. Giblon and Rolih [Ref. 1] studied the commercial ship application of COGAS. References 2 and 3 investigated the feasibility of the COGAS system for military ship application. In all three studies the COGAS system was designed around a gas turbine brake horsepower of about 23,000. Additionally, all three employed a drum-type boiler as the waste heat recovery unit.

In this study, COGAS system designs were considered for a destroyer-sized ship with two shafts and two LM-2500 gas turbines for each shaft. One gas turbine was equipped with a WHRU. In the COGAS mode of operation the WHRU-equipped gas turbine was operated in parallel with the steam turbine,



COGAS SYSTEM

FIGURE 1

powering one shaft. The other shaft was allowed to drag. It was assumed that the principal employment of the COGAS system would be for "cruise" conditions. That is, the COGAS system would be operated primarily for steady steaming. The horsepower range over which the COGAS system could be operated is, theoretically, limited only to the range of powers over which the gas turbine can be operated. Thus, the power range would vary from the COGAS system power output with the gas turbine at idle to the system power output attained with the gas turbine operating at its maximum continuous power rating.

When the COGAS system operating range is selected, the desired goal of fuel conservation must be balanced against system reliability and routine maintenance requirements. If only one gas turbine is equipped for COGAS operations, the system downtime will increase as the turbine is operated at higher power settings. In order to increase the time between major gas turbine maintenance requirements, two COGAS systems could be installed in a twin-shaft ship. The increased overall reliability which this redundancy would afford, however, would be at least partially offset by the higher initial cost, the increased manning requirements, and the added weight of two systems.

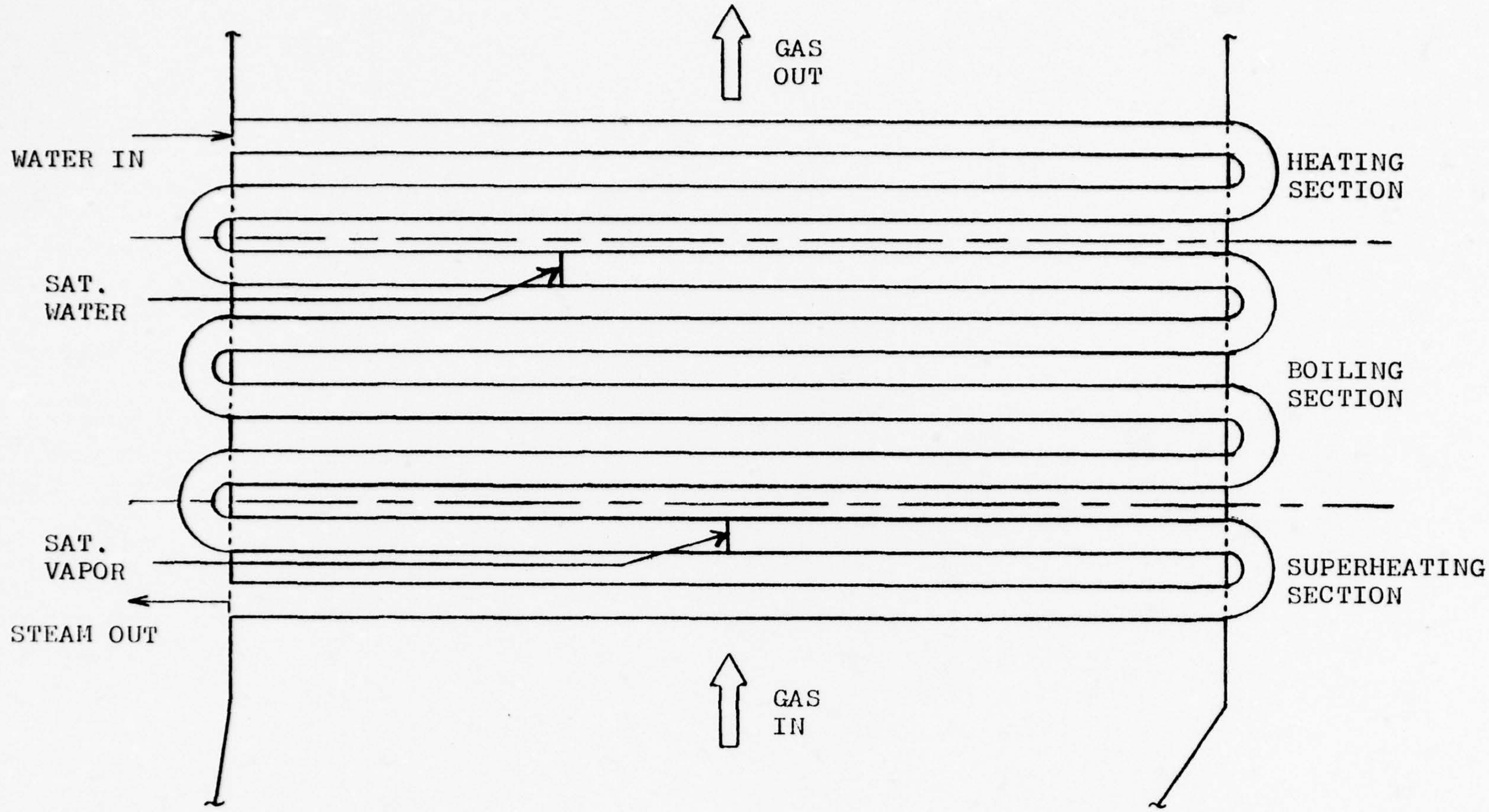
A once-through counter-cross-flow heat exchanger was selected as the WHRU. Reference 6 states some of the principal advantages of the once-through steam generator over the drum-type boiler. These advantages are as follows:

lower initial cost, faster response, more compactness, and lower operating cost. Additionally, the once-through unit provides a somewhat simpler model than the drum-type heat exchanger. A schematic representation of a once-through WHRU installed in the exhaust ducting of a gas turbine is shown in figure 2.

B. OBJECTIVES

There were five main objectives for this thesis.

1. Develop a design model for the once-through WHRU. This model was to size a WHRU and predict is performance given initial conditions such as feedwater inlet temperature, steam outlet temperature, WHRU operating pressure, inlet and outlet gas conditions, and gas flow rate.
2. Consider several sets of initial conditions and design constraints (e.g., maximum frontal dimensions) and produce WHRU designs for each set.
3. Evaluate these designs and integrate them with a simple COGAS system model in order to test the design model and to develop a clearer understanding of the WHRU performance in the COGAS system.
4. From the evaluated designs, predict the performance of the COGAS system.
5. Provide a framework for future studies involving a detailed, complete COGAS system cycle analysis and optimization.



ONCE-THROUGH WASTE HEAT RECOVERY UNIT

FIGURE 2

II. MODEL DESCRIPTION

A. OVERVIEW AND INITIAL CALCULATIONS

The waste heat recovery unit (WHRU) is modeled as a once-through counter-cross-flow heat exchanger. The model is applied in a computer program for use in heat exchanger design for a combined gas and steam (COGAS) turbine propulsion plant system. The same model could be adapted for use in a complete cycle analysis of the COGAS system.

The WHRU model is divided into three principal sections: heating, boiling and superheating. The specified initial conditions for the model are: (1) gas temperature into the heat exchanger (T_{g1}), (2) minimum average gas exit temperature from the heat exchanger (T_{g4}), (3) gas flow rate ($\dot{m}_g$), (4) water inlet temperature (T_{f1}), (5) water/steam pressure (P_f). Useful background material for the model formulation was obtained from references 1-5.

Two simplifications should be noted at this point. First, the water-side pressure drop in the WHRU is neglected. Second, gas temperatures, evaluated at several points in the model, are average temperatures. Specifically, the average inlet and outlet gas temperatures for the heating and superheating sections and the average inlet and outlet gas temperatures for each pass in the boiling section are evaluated. In each of these calculations the gas temperature distribution is neglected. Clearly, even if the gas

turbine exhaust flow is uniform in temperature as it approaches the WHRU, the gas temperature will not be uniform after the first WHRU pass is encountered. Due to the varying gas-to-fluid temperature difference across each pass the gas temperature will be distributed non-uniformly after the first WHRU pass. One can, however, calculate the average gas temperature approaching a particular pass based on the heat release from the gas in the previous pass and the average gas temperature entering the previous pass. Averaged gas temperatures calculated in this manner are used throughout the model.

Prior to the heating section, some initial calculations are performed to determine the water/steam mass flow rate and to set the pinch point. In order to calculate the water/steam mass flow rate an energy balance is performed, using the starting conditions, as follows:

$$Q = \dot{m}_g C_{pg}(T_{g1} - T_{g4})$$

where C_{pg} is evaluated at the average gas temperature $T_{gavg} = (T_{g1} + T_{g4})/2$. The fluid mass flow rate is calculated from

$$\dot{m}_f = \frac{Q}{h_{f4} - h_{f1}}$$

where h_{f1} and h_{f4} are inlet and outlet fluid enthalpy

respectively. Intermediate fluid and gas temperatures are calculated as follows:

1. The heating section is assumed to heat the water from inlet conditions to the saturation temperature, T_{f2}. A heat balance is performed on the water side yielding a heating section heat transfer of

$$Q_h = \dot{m}_f (h_{f2} - h_{f1}) .$$

The required average gas temperature entering the heating section is then calculated from

$$T_{g3} = T_{g4} + \frac{Q_h}{\dot{m}_g \; C_{pg}} .$$

2. In the boiling section it is assumed that sufficient heat is added to produce saturated vapor at the outlet. An energy balance on the steam-side provides the total heat transfer in the boiling section,

$$Q_b = \dot{m}_f (h_{f3} - h_{f2})$$

where h_{f3} is the enthalpy of saturated vapor at the pressure specified. The required average gas temperature entering the boiling section is

$$T_{g2} = T_{g3} + \frac{Q_b}{\dot{m}_g \; C_{pg}} .$$

3. In the superheating section, the steam temperature is raised from the saturation temperature to the outlet temperature specified in the initial conditions. The heat transfer in the superheating sections is

$$Q_{sh} = \dot{m}_f (h_{f4} - h_{f3})$$

where h_{f4} is the enthalpy of steam corresponding to the steam outlet temperature T_{f4}. The gas inlet temperature T_{g1} is known from the initial conditions.

The "pinch point", for the purposes of this model, is defined as the difference between the gas temperature entering the heating section and the water temperature leaving the heating section (saturation temperature). This temperature difference will normally correspond to the smallest temperature difference between gas and fluid in the heat exchanger. The only other likely location for the smallest temperature difference between gas and fluid is at the gas inlet, or superheater outlet. Figure 3 depicts the typical gas and fluid temperature distribution in the WHRU.

The model must provide some internal control over the pinch point temperature difference as defined above. This is desirable because the gas-fluid temperature difference at the fluid saturation point is indicative of the amount of heat transfer area which will be necessary to heat the incoming water to the saturation point. As the temperature

TYPICAL WHRU GAS-FLUID TEMPERATURE DISTRIBUTION

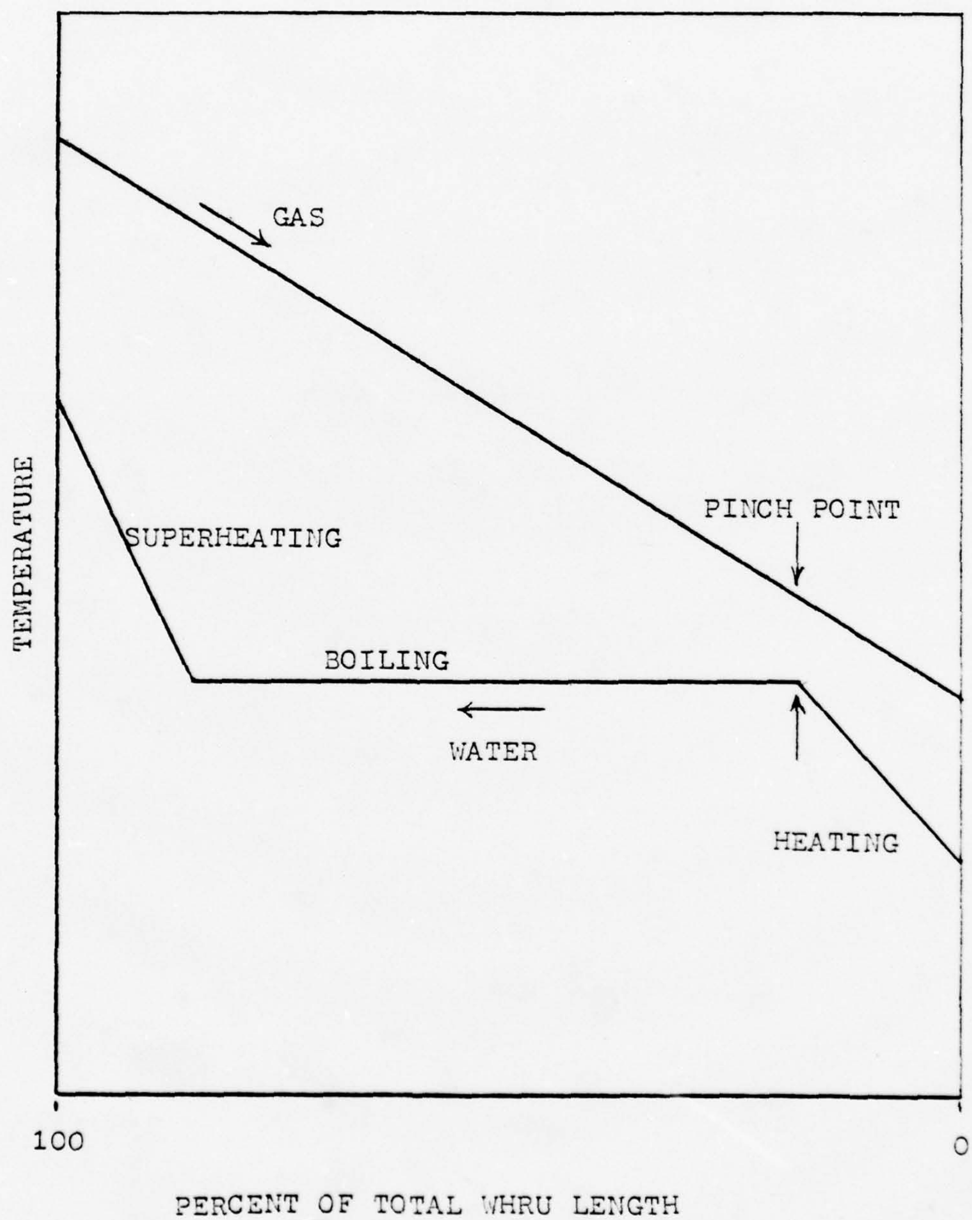


FIGURE 3

difference at the pinch point increases the heating portion of the heat exchanger becomes more efficient from the point of view of heat transfer area required. The minimum pinch point temperature difference is set at 25 F. After the interim temperatures are established the pinch point temperature difference is checked. If the difference is less than 25 F, the gas temperature at the heating section inlet is reset to

$$T_{g3} = T_{f2} + 25.$$

From the overall energy balance

$$C_{pg}\,\dot{m}_g(T_{g1} - T_{g4}) = \dot{m}_f(h_{f4} - h_{f1})$$

and the energy balance across the heating section

$$C_{pg}\,\dot{m}_g(T_{g3} - T_{g4}) = \dot{m}_f(h_{f2} - h_{f1}),$$

a revised gas outlet temperature may now be calculated from

$$T_{g4} = \frac{T_{g3} - \alpha T_{g1}}{1 - \alpha}$$

where

$$\alpha = \frac{h_{f2} - h_{f1}}{h_{f4} - h_{f1}}.$$

After this new gas inlet temperature is established, all initial calculations are performed again, to establish a new water/steam mass flow rate and to recheck the pinch point temperature difference. Once these calculations are complete, the geometric parameters for the heat exchanger must be specified.

B. GEOMETRY

A fin-tube with helically curved extended surfaces on circular tubes is assumed for this model. The fins are segmented. The tubes are configured in banks of one row each and the rows are staggered. The base tube surface is taken from Ref. 7. The description of the finned tubes is as follows.

d_i = tube inside diameter = 1.86 in.

d_o = tube outside diameter = 2.00 in.

d_r = fin root diameter = 2.00 in.

N_f = fins per inch = 5.94

ℓ = fin height = 1.015 in.

ℓ_c = length of cut from fin tip = 0.82 in.

d_f = fin outside diameter = 4.03 in.

t_f = fin thickness = 0.048 in.

w_s = fin segment width = 0.17 in.

N_s = number of segments in 360 degrees = 38

The finned tube configuration is shown in figure 4. The tube length, L, and number of tubes per row $N_{t/r}$ are chosen by the designer according to the frontal area, A_f,

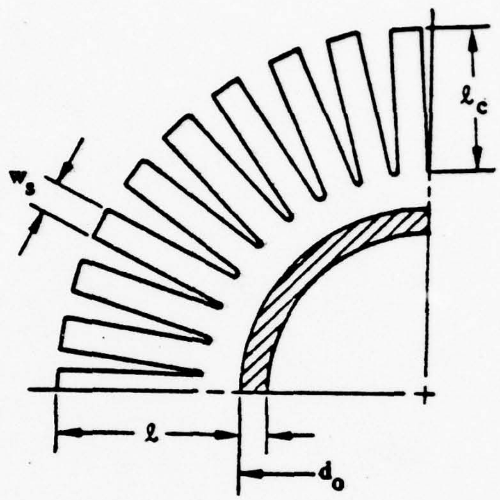


Figure 4: Segmented Fin-Tube Configuration

desired. The tube layout is shown below in figure 5. The center-to-center tube spacing in the transverse direction is 4.50 inches. The equilateral, staggered tube arrangement used in this model leads to a spacing normal to the gas flow, S_n, of 4.50 inches and a spacing parallel to the gas flow, S_p, of 3.90 inches as shown in figure 5. The heat exchanger height is established by the number of WHRU passes (rows) and the tube spacing parallel to the gas flow (S_p).

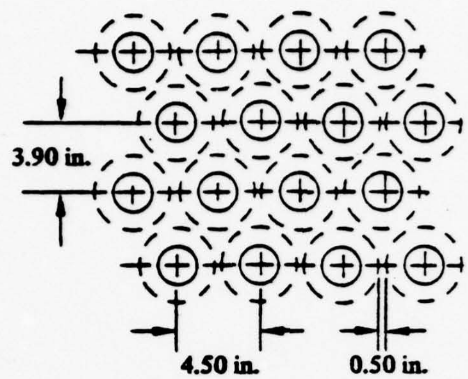


Figure 5: Model Tube Layout

In order to establish the minimum gas flow cross-sectional area the total "blocked" frontal area, A_b, of the heat exchanger must be calculated from

$$A_b = N_{t/r} \, L \, d_o + L \, N_f \, L \, N_{t/r} \, \ell \, t_f \, ,$$

and the minimum gas flow area is

$$A_{min} = A_f - A_b$$

The total inside area available for heat transfer per pass is

$$A_{ip} = \pi \, d_i \, L \, N_{t/r} \, .$$

The gas side surface area available per pass for heat transfer is the sum of the fin surface area and the bare tube surface area per pass. The fin surface area per tube is calculated from

$$A_{fin} = N_f \, L[N_s(2\,\ell_c\,w_s + 2\,t_f\,\ell_c + w_s\,t_f) - \frac{\pi}{2}(d_{fb}^2 - d_o^2)]$$

where $d_{fb} = d_f - 2\ell_c$. The bare tube area per tube is

$$A_{bt} = \pi\,d_o\,L - \pi\,d_o\,t_f\,N_f\,L\ .$$

Therefore, the total outside area per pass available for heat transfer is

$$A_{op} = N_{t/p}(A_{fin} + A_{bt})\ .$$

The cross-sectional area for fluid flow is calculated from

$$A_{ff} = \frac{\pi}{4}\,d_i^2\,N_{t/p}\ .$$

With the mass flow rates, terminal temperatures and heat exchanger geometry established, the remainder of the model may be solved for number of passes, actual interim temperatures, location of the fluid phase changes, and the gas side pressure drop.

C. HEATING SECTION

The gas-side Reynolds number for the heating section is calculated initially using the gas bulk temperature to find the gas properties. With this Reynolds number, a j-factor and a friction factor, f, are obtained from polynomials fit to the data for tube layout number 5 in Ref. 7 (fig. 5). The friction factor will be used later to calculate the gas side pressure drop in the heating section. The j-factor is related to the heat transfer coefficient h_g by the following relationship.

$$j = S_t \, P_r^{2/3}$$

By introducing

$$S_t = \frac{N_u}{R_e \, P_r}$$

the previous expression can be written as

$$j = \frac{N_u}{R_{eg} \, P_{rg}} \, P_r^{2/3} = \frac{N_u}{R_{eg} \, P_{rg}^{1/3}} ,$$

and

$$N_u = j \, R_{eg} \, P_{rg}^{1/3} ,$$

where

$$N_u = \frac{h_g\, d_o}{K_g}.$$

Therefore, a relationship may be written for the heat transfer coefficient as follows:

$$h_g = j\, \frac{K_g}{d_o}\, R_{eg}\, P_{rg}^{1/3} .$$

The water-side heat transfer coefficient is calculated by using the Dittus-Boelter correlation

$$h_f = 0.023\, \frac{K_f}{d_i}\, R_{ef}^{0.8}\, P_{rf}^{0.4}$$

where all properties are obtained at the bulk temperature of the water in the heating section. Using the tube wall resistance together with h_g and h_f, the overall heat transfer coefficient for the heating section may be written in terms of the inside area as

$$U_{oi} = \frac{1}{\frac{1}{h_f} + \frac{A_{ip}\, \ln(d_o/d_i)}{2\,\pi\, K_w\, N_{t/p}\, L} + \frac{A_{ip}}{A_{op}}\, \frac{1}{\eta_t\, h_g}}$$

where

$$\eta_t = 1 - (1 - \eta_f)\, \frac{A_{fin}}{A_{op}} .$$

The fin efficiency, η_f, is calculated from the expression

$$\eta_f = \frac{\tanh ML}{ML} ,$$

where

$$M = \sqrt{h_g P/KA}$$

and, if the fin is approximated by a set of rectangular strips extending from the tube wall, $L = \frac{d_f - d_o}{2}$. Now, the cross-sectional area, A, of a rectangular strip may be written as

$$A = w_s \, t_f ,$$

and the perimeter is

$$P = 2(w_s + t_f).$$

So, using known geometric parameters and the thermal conductivity of the fin metal, the parameter ML may be expressed as

$$ML = C \sqrt{h_g}$$

where

$$C = \left(\frac{d_f - d_o}{2}\right)\sqrt{\frac{2(w_s + t_f)}{w_s\, t_f\, K}} .$$

Now,

$$\eta_t = [1 - (1 - \frac{\tanh C\sqrt{h_g}}{C\sqrt{h_g}})\frac{A_{fin}}{A_{op}}] .$$

The number of passes required in the heating section is calculated, using the effectiveness-NTU method, in the following way.

1. An average pass effectiveness for the heating section is calculated from the following expression for cross-flow effectiveness with both fluids unmixed obtained from Ref. 8,

$$\varepsilon_p = 1 - \exp[\frac{\exp(-NC\eta) - 1}{C\,\eta}]$$

where

$$C = \frac{C_{min}}{C_{max}} = \frac{C_{pf}\,\dot{m}_f}{C_{pg}\,\dot{m}_g} ,$$

$$N = NTU = \frac{U_{oi}\,A_{ip}}{C_{min}} ,$$

$$\eta = N^{-0.22} .$$

Water and gas properties are taken at bulk temperatures.

2. An overall heating section effectiveness is calculated from

$$\varepsilon_{oa} = \frac{\left(\frac{1 - \varepsilon_p C_{min}/C_{max}}{1 - \varepsilon_p}\right)^n - 1}{\left(\frac{1 - \varepsilon_p C_{min}/C_{max}}{1 - \varepsilon_p}\right)^n - \frac{C_{min}}{C_{max}}}$$

where n = number of passes. This expression was obtained from Ref. 9. The overall effectiveness formulation was actually derived with the condition that fluids are mixed between passes. It can be shown [Ref. 9], however, that the error is not large when the expression is used for the case where fluids are unmixed between passes.

3. The expression for ε_{oa} is now used in an iterative fashion starting with n = number of passes = 1. Each time ε_{oa} is solved, the gas temperature into the heating section, T_{g3}, is found from

$$T_{g3} = \frac{\varepsilon_{oa} C_{min} T_{g1} - C_{max} T_{g4}}{\varepsilon_{oa} C_{min} - C_{max}}$$

which is derived from

$$\varepsilon_{oa} = \frac{C_{max}(Tg_3 - T_{g4})}{C_{min}(T_{g3} - T_{f1})} .$$

4. Once the inlet gas temperature is established for a particular number of passes, an energy balance may be

performed to solve for the total heat transfer which would take place in the heating section for that number of passes.

$$Q_h = \dot{m}_g C_{pg}(T_{g3} - T_{g4})$$

5. The enthalpy of the water at the outlet of the heating section for a particular iteration may be found from

$$h_{fL} = h_{f2} + \frac{Q_h}{\dot{m}_f},$$

and this yields the temperature of the water at the outlet, T_{f2}, for the number of passes under consideration.

6. The outlet water temperature, T_{f2}, may be checked to see if it exceeds the saturation temperature.

7. This set of calculations is performed until T_{f2} exceeds the saturation temperature. This naturally means that boiling begins in the last pass of the current total number of passes. Initiation of boiling will be treated in the boiling section of the model. Therefore, the heating section ends with the pass prior to that which initiates boiling. The results of the above calculations are: (a) The total number of passes contained in the heating section, (b) the new gas temperature at the inlet to the heating section T_{g3}, and (c) the new water outlet temperature T_{f2}.

With these new heating section terminal temperatures an average outside wall temperature for the section may be calculated from

$$T_{wo} = T_{gb} - \left(\frac{U_{oi} A_{ti}}{h_g A_{to}}\right)(T_{gb} - T_{fb})$$

where A_{ti}/A_{to} are total inside/outside areas for the section and T_{gb}/T_{fb} are the new gas/fluid bulk temperatures for the section. The expression for T_{wo} is derived from the following formulation for heat transfer in the heating section,

$$Q = \frac{T_{gb} - T_{fb}}{\sum R_{th}} = \frac{T_{gb} - T_{wo}}{R_o}$$

which reduces to

$$T_{wo} = T_{gb} - \frac{R_o}{\sum R_{th}}(T_{gb} - T_{fb})$$

where

$$R_o = \frac{1}{\eta_t h_g A_{to}}$$

and

$$\sum R_{th} = \frac{1}{U_{oi} A_{ti}} .$$

The gas-side film temperature is

$$T_{gf} = \frac{T_{gb} - T_{wo}}{2} .$$

This gas-side film temperature is now introduced at the beginning of the calculations for the heating section, to replace the gas bulk temperature. All calculations are performed again with T_{gf}.

The gas-side pressure drop in the heating section may now be calculated using the previously obtained friction factor, f, from the correlation contained in Ref. 7. The gas-side pressure drop is

$$\Delta P_g = \frac{2f\ G_{max}^2\ N_{t/r}}{\rho} \left(\frac{\mu_w}{\mu_b}\right)^{0.14}$$

where

$$G_{max} = \frac{\dot{m}_g}{A_{min}}$$

$N_{t/r}$ = number of tubes per row

ρ = gas density

μ_w = gas viscosity at wall temperature

μ_b = gas viscosity at bulk temperature.

D. BOILING SECTION

The boiling section is solved pass-by-pass since most of the section will involve two-phase flow on the cold side and the inside heat transfer coefficient will change with quality, x, and heat flux, q". The correlation for the two-phase region inside heat transfer coefficient selected

for this model is that recommended by Tong [Ref. 10] for both nucleate boiling and forced convection. The equation for the two-phase flow heat transfer coefficient was given by Schrock and Grossman in Tong [Ref. 10] as

$$\frac{h_{TPf}}{h_{\ell}} = B\left[\frac{q''}{G\,h_{fg}} + A\left(\frac{1}{X_{tt}}\right)^{n}\right] .$$

The constants are given by Wright [Ref. 10]: $B = 6.70 \times 10^{3}$, $A = 3.5 \times 10^{-4}$, $n = 0.66$. The heat transfer coefficient assuming a total liquid flow is

$$h_{\ell} = 0.023\,\frac{K_{\ell}}{d_i}\left[\frac{d_i\;G(1-x)}{\mu_{\ell}}\right]^{0.8}\left[\frac{C_{p\ell}\;\mu_{\ell}}{K_{\ell}}\right]^{0.1},$$

and the Martinelli parameter is

$$\frac{1}{X_{tt}} = \left[\frac{x}{1-x}\right]^{0.9}\left[\frac{\rho_{\ell}}{\rho_v}\right]^{0.5}\left[\frac{\mu_v}{\mu_{\ell}}\right]^{0.1} .$$

The limits of the data for this correlation are

quality: 0.05 - 0.57

heat flux: $6.0 \times 10^{4} - 1.45 \times 10^{6}$ BTU/hr-ft^2.

In this model, heat flux in the boiling section will be at levels considerably below 6×10^{4} BTU/hr-ft^2 and the full range of quality must be considered. Therefore, in order to observe the performance of the Schrock and Grossman correlation at lower heat flux and quality above 0.57 a plot was made (fig. 6) of the ratio h_{tpf}/h_{ℓ} vs. quality

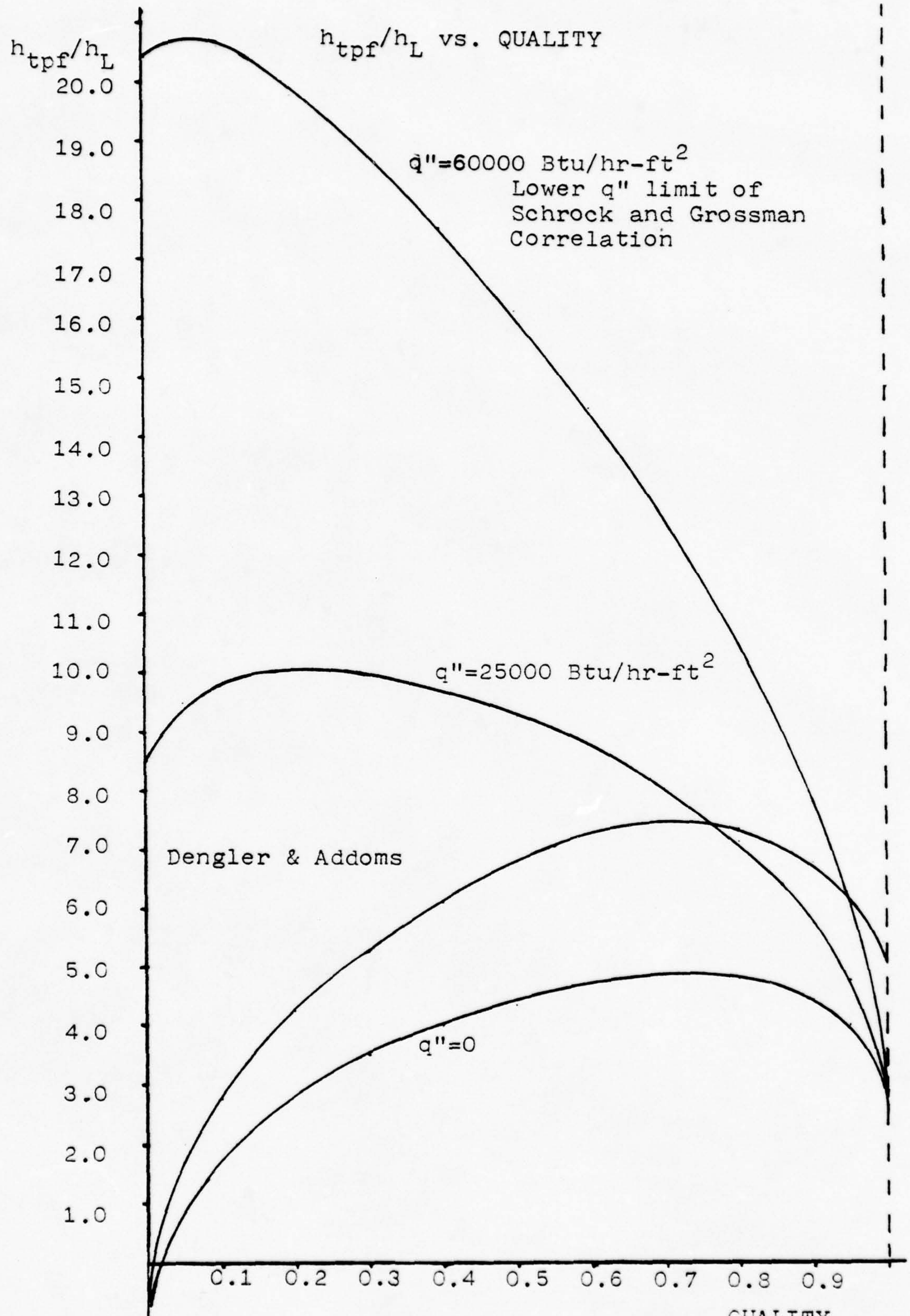

h_{tpf}/h_L vs. QUALITY
h_{tpf}/h_L
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
q"=60000 Btu/hr-ft^2
Lower q" limit of Schrock and Grossman Correlation
q"=25000 Btu/hr-ft^2
Dengler & Addoms
q"=0
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
QUALITY

FIGURE 6

where h_l is the heat transfer coefficient from the Dittus-Boelter correlation for water at saturated liquid conditions. The correlation of Dengler and Addoms as given in Tong [Ref. 10] for entirely forced convection vaporization is included for comparison. Tong [Ref. 10] indicates that low heat flux and high water-vapor mixture velocity favor the forced convection mechanism. After a review of the information available in Tong, it is not entirely clear whether the forced convection mechanism or the nucleate boiling mechanism is dominant for the relatively low flow velocities and low heat flux of this model. In any case, the Schrock and Grossman correlation applied at low heat flux represents a type of compromise between the entirely forced convection assumptions of Dengler and Addoms and the "mixed" assumption of Schrock and Grossman. When the Schrock and Grossman correlation is applied under the conditions of very low heat flux and quality ($x < 0.05$), as in the first pass of the boiling section of this model, it can be seen that the ratio h_{tpf}/h_l becomes less than one. This is both unrealistic and computationally difficult to handle. Therefore, in the boiling section, the model assumes that $h_{tpf} = h_l$ for the first pass or for any pass where $x < 0.05$. This assumption will produce a more realistic but still conservative design.

One other simplification should be explained prior to discussion of the actual model calculations for the boiling section. Since the boiling section calculations are performed

for one complete pass at a time, the average quality, x_a, in a particular pass is used as the "local" quality to compute the inside heat transfer coefficient from the Schrock and Grossman correlation.

The first pass in the boiling section, as indicated in the calculations for the heating section, will, in general, involve both heating water to the saturation temperature and the initiation of boiling. From the calculations for the last pass of the heating section we have the following quantities for the first pass of the boiling section: water inlet temperature (T^1_{fin}), average gas outlet temperature ($T^1_{g_{out}}$). The gas side heat transfer coefficient, h_g, is obtained, using the average gas temperature in the boiling section, in the same way as for the heating section.

A rough estimate for the gas temperature into the first pass must be obtained in order to begin calculations for that pass. This is accomplished by calculating a rough overall heat transfer coefficient, U^1_{oi}, for the pass using the tube wall resistance, h_g, and neglecting inside resistance. A pass effectiveness, ε^1_p, is then calculated assuming that only boiling takes place in the pass. The expression for effectiveness for fluids unmixed between passes for C = 0 becomes

$$\varepsilon_p = (1 - \exp(-N)$$

where N = NTU. Using ε_p calculated from this expression, the rough gas temperature for the first pass is

$$T_{g_{in}}^1 = \frac{\varepsilon_p^1 T_{f_{in}}^1 - T_{g_{out}}^1}{\varepsilon_p^1 - 1}.$$

Since this pass has been simplified by allowing the inside heat transfer coefficient to be computed by the Dittus-Boelter correlation this initial guess for $T_{g_{in}}^1$ is not essential. It would, however, become important if we were attempting to "split" the pass with two inside heat transfer coefficients, one for heating and one for boiling. Instead, the inside heat transfer coefficient, h_f^1, is calculated for the entire pass using the Dittus-Boelter correlation with water conditions corresponding to the average water conditions in the heating section of the pass, that is,

$$T_{f_{avg}}^1 = \frac{T_{f_{in}}^1 + T_{satf}}{2} .$$

With this inside heat transfer coefficient, an expression for the overall heat transfer coefficient for the first pass may be written,

$$U_{oi}^1 = \frac{1}{\frac{1}{h_f^1} + \frac{A_{ip}}{2\,\pi\, K_w} \frac{\ln(d_o/d_i)}{N_{t/p}\, L} + \frac{A_{ip}}{A_{op}} \frac{1}{h_g^1\, \eta_t}}$$

The pass effectiveness, ε_p^1, is now calculated in the same manner as previously described. With ε_p^1, the average gas

temperature in is calculated from

$$T^1_{g_{in}} = \frac{\varepsilon^1_p C_{min} T^1_{f_{in}} - C_{max} T^1_{g_{out}}}{\varepsilon^1_p C_{min} - C_{max}} .$$

The pass heat transfer may be calculated from

$$Q^1_p = \dot{m}_g C_{pg}(T^1_{g_{in}} - T^1_{g_{out}}) .$$

The expression for out let enthalpy from the pass is

$$h^1_{f_{out}} = h^1_{f_{in}} + \frac{Q^1_p}{\dot{m}_f} ,$$

and outlet quality is calculated from

$$x^1_{out} = \frac{h^1_{f_{out}} - h_{satf}}{h_{fg}} .$$

In order to determine the location of the interface between heating and boiling the total inside area devoted to heating in the first pass is calculated from

$$A^1_{ih} = \left(\frac{h_{satf} - h^1_{f_{in}}}{h^1_{f_{out}} - h^1_{f_{in}}}\right) A_{ip} .$$

Subsequent fluid passes in the boiling section are calculated until the quality at the outlet of a pass is found to be greater than 1.0. When this occurs, the boiling section is allowed to end with the last pass for which $x_{out} \leq 1.0$. A "mixed" pass where both boiling and superheating

takes places will be calculated in the superheating section of the model.

After the first pass, boiling section fluid passes are calculated in the following manner.

1. The steam quality at the outlet of the previous pass becomes the inlet quality for the current pass, x_{in}. The average gas temperature at the inlet to the previous pass becomes the outlet average gas temperature, $T_{g_{out}}$, for the current pass.

2. Using the last overall heat transfer coefficient calculated for the previous pass, U_{oi}, approximate values of NTU and ε_p are calculated.

3. With this approximate ε_p the average gas temperature into the current pass is calculated from

$$T_{g_{in}} = \frac{\varepsilon_p T_{f_{sat}} - T_{g_{out}}}{\varepsilon_p - 1}.$$

4. Using this gas temperature in, $T_{g_{in}}$, the pass heat transfer, Q_p, is calculated. This allows the calculation of enthalpy out, $h_{f_{out}}$, and quality out, x_{out}, as well as the average quality in the current pass, x_a.

5. The inside heat transfer coefficient, h_{tpf}, may now be calculated,

$$h_{tpf} = B[\frac{Q_p/A_{ip}}{G\ h_{fg}} + A(\frac{1}{x_{tt}})^n]\ h_\ell ,$$

where the Martinelli parameter $\frac{1}{X_{tt}}$ is calculated using average quality, x_a, and all other terms are as previously described.

6. A new overall heat transfer coefficient is now calculated from which a new pass effectiveness can be calculated.

7. This new pass effectiveness yields a new average gas temperature into the pass from which a new pass heat transfer may be calculated.

8. The new pass heat transfer is compared with the previously calculated pass heat transfer. If the two heat transfer calculations do not agree to within 5% the entire set of calculations is repeated.

9. When the pass heat transfer calculation converges, the final quality at the outlet of the pass is calculated. If the quality is less than 1.0 another pass is calculated for the boiling section.

10. If the quality is 1.0, the boiling section ends with the current pass. If the quality out exceeds 1.0 the boiling section ends with the previous pass.

Calculations for the average gas film temperature and gas-side pressure drop are performed in the same manner as for the heating section.

E. SUPERHEATING SECTION

The first pass of the superheating section will, in general, involve both boiling and superheating. The inside heat transfer coefficients will be quite different for the

boiling and superheating portions for the pass, and, for this reason, the pass will be "split" to allow more accurate calculation of the heat transfer in these two regions. An outline of the calculation scheme is as follows:

1. Calculate the gas-side heat transfer coefficient for the section in the same manner as for the previous two sections.

2. Estimate the average gas temperature into the first pass. This is only a rough guess for $T_{g_{in}}$, to begin the calculation.

3. Calculate the required heat transfer in the boiling portion

$$Q_{rb} = \dot{m}_f(h_{f_{in}} - h_{satv})$$

where $h_{f_{in}}$ is the enthalpy out of the last pass of the boiling section and h_{satv} is the enthalpy of saturated vapor.

4. Using Q_{rb} and the average quality in the boiling portion of the first pass, calculate the inside heat transfer coefficient, h_{tpf}, using the Schrock and Grossman correlation, as in the boiling section of the model. This, together with the gas-side heat transfer coefficient and the wall resistance, will yield an overall heat transfer coefficient for the boiling section, U_{oi}^{b}.

5. The calculation of the area required for the boiling portion of the pass is performed in an iterative scheme as follows.

a. An initial estimate for the required boiling area, Al, is made.

b. The mass flow rate of the gas over the boiling portion is then

$$\dot{m}_g^b = \frac{Al}{A_{ip}} \dot{m}_g .$$

c. An effectiveness for the boiling portion may be calculated from

$$\varepsilon_b = \frac{Q_{rb}}{C_{min}^b (T_{g_{in}} - T_{f_{sat}})}$$

where

$$C_{min}^b = \dot{m}_g \, C_{pg}.$$

d. Using the previously calculated overall heat transfer coefficient, the estimated boiling area and the consequent gas-side heat capacity, NTU is calculated from

$$NTU = \frac{U_{oi}^b \, Al}{C_{min}^b} .$$

e. A "test" effectiveness, ε_b^t, can be found by applying this NTU in the relationship for effectiveness

$$\varepsilon_b^t = 1 - \exp(NTU).$$

f. The two effectiveness calculations, ε_b and ε_b^t, are compared.

(1) If ε_b^t is greater than ε_b, then the original estimate for the boiling area, Al, was too large for the heat transfer required and the specified gas temperature into the pass. So, the estimate for the boiling area is decreased and a new Al is established.

(2) If ε_b^t is less than ε_b, Al is increased.

g. A new gas-side heat capacity is calculated from

$$C_{min}^{b} = \frac{Al}{A_{ip}} \dot{m}_g \, C_{pg} \; .$$

h. A new boiling portion effectiveness is calculated using the latest boiling area estimate

$$\varepsilon_b = \frac{Q_{rb}}{C_{min}^{1}(T_{g_{in}} - T_{f_{sat}})} \; .$$

i. As before, an NTU is calculated with the new Al. This generates a new "test" effectiveness, ε_b^t, which is compared with ε_b. If ε_b and ε_b^t are not equal, a new Al is calculated based on the comparison.

j. These calculations are continued until $\varepsilon_b \doteq \varepsilon_t$. The current Al is then set equal to A_i^b.

6. Once the area required for boiling, A_i^b, for a particular average gas inlet temperature has been established, the following first pass quantities can be calculated:

a. A_i^{sh} = area available for superheating

$$A_i^{sh} = A_{ip} - A_i^b$$

b. $\dot{m}_g^b$ = gas flow rate over the boiling portion

c. $\dot{m}_b^{sh}$ = gas flow rate over the superheating portion

d. $T_{g_{out}}^b$ = gas temperature out of the boiling portion

$$T_{g_{out}}^b = T_{g_{in}} - \frac{Q_{rb}}{\dot{m}_g^b \, C_{pg}}$$

e. $T_{g_{out}}^{sh}$ = gas temperature out of the superheating portion

$$T_{g_{out}}^{sh} = \frac{A_{ip} \, T_{g_{out}} - A_i^b \, T_{g_{out}}^b}{A_i^{sh}}$$

(The weighted average of $T_{g_{out}}^{sh}$ and $T_{g_{out}}^b$ must equal the $T_{g_{out}}$ previously calculated.)

7. Since the heat transfer to the cold side must satisfy an energy balance involving the average temperatures of the gas, the expected heat transfer in the superheating portion may be calculated from the heat release on the gas side

$$Q_p = \dot{m}_g \, C_{pg} (T_{g_{in}} - T_{g_{out}}),$$

and the required heat transfer in the superheating portion as

$$Q_{sh} = Q_p - Q_{rb} .$$

8. The enthalpy and temperature of the steam out of the first pass may be calculated from the assumed heat transfer in the superheating portion, Q_{sh}.

9. The steam properties for the superheating portion may now be found. These properties, along with h_g and wall resistance, will yield an overall heat transfer coefficient, U_{oi}^{sh}, for the superheating portion. The Dittus-Boelter correlation is applied to calculate the inside heat transfer coefficient.

10. The heat capacities on the gas and fluid sides are calculated, using the current gas mass flow rate over the superheating portion, $\dot{m}_g^{sh}$, to calculate the gas heat capacity. The heat capacities along with U_{oi}^{sh} and A_i^{sh} yield the effectiveness for the superheating portion of the pass, ε_{sh}.

11. A new average gas temperature into the pass may now be calculated from the superheating portion effectiveness and the superheating portion heat transfer required to satisfy the original heat balance from the expression

$$T^*_{g_{in}} = T_{f_{in}} + \frac{Q_{sh}}{\varepsilon_{sh}\, C_{min}^{sh}} .$$

This temperature, $T^*_{g_{in}}$, is a measure of the temperature which would be required to produce the originally specified Q_{sh} under the actual conditions of the heat transfer characteristics of the superheating portion.

12. If the $T^*_{g_{in}}$ is the same as the originally specified average gas temperature into the pass, $T_{g_{in}}$, then the heat transfer in the superheating portion, Q_{sh}, is possible under the current distribution of area between boiling and superheating and the heat balance is satisfied between steam and gas sides for the specified gas temperature in. In this event, the calculations for the first pass of the superheating section are complete.

13. If $T^*_{g_{in}}$ is less/greater than the current $T_{g_{in}}$ the average gas temperature into the pass is increased/decreased and the entire set of calculations is performed again until $T^*_{g_{in}} \doteq T_{g_{in}}$.

14. The second and subsequent superheating section passes are calculated in much the same way as in the heating section. That is, an overall pass effectiveness is calculated for a specified number of passes, using the multipass effectiveness relationship from Kays and London [Ref. 9].

15. The average steam-side heat transfer coefficient, h_f, is calculated using the Dittus-Boelter correlation with steam properties at steam bulk temperature for the remainder of the superheating section. The overall heat transfer coefficient and the average pass effectiveness, ε_p, are then calculated.

16. The formulation for overall effectiveness with the number of passes, n, variable, is

$$\varepsilon_{oa} = \frac{\left(\frac{1 - \varepsilon_p C_{min}/C_{max}}{1 - \varepsilon_p}\right)^n - 1}{\left(\frac{1 - \varepsilon_p C_{min}/C_{max}}{1 - \varepsilon_p}\right)^n - \frac{C_{min}}{C_{max}}} .$$

As in the heating section this expression is used in an iterative fashion, beginning with n = 1.

17. Each time ε_{oa} is solved, the gas temperature into the superheating section is calculated from

$$T_{g_{in}} = \frac{\varepsilon_{oa} C_{min} T_{f_{in}} - C_{max} T_{g_{out}}}{\varepsilon_{oa} C_{min} - C_{max}}$$

where $T_{f_{in}}$ is the temperature of the steam into the second pass of the superheater and $T_{g_{out}}$ is the average gas temperature out of the second pass of the superheater. This gas temperature in is compared with the originally specified gas temperature into the heat exchanger, T_{g1}.

18. If the calculated gas temperature in, $T_{g_{in}}$, is less than T_{g1} the number of passes is increased by one and the calculation is performed again. If $T_{g_{in}}$ exceeds T_{g1}, the superheater is allowed to stop with the previous pass.

Calculations for the average gas film temperature and the gas-side pressure drop are performed in the same manner as for the heating and boiling sections.

F. MATCHING SUPERHEATER GAS INLET TEMPERATURE

The model calculations thus far lead to a waste heat recovery unit design for which the gas temperature at the

inlet is, in general, lower than that specified in the initial conditions. This condition occurs because the superheater ends with the last complete pass calculated for which the entering gas temperature is less than or equal to the originally specified WHRU inlet temperature. This outcome is, of course, unsatisfactory since the inlet gas temperature is an independent quantity which is a function of the horse-power setting on the gas turbine. An iterative scheme is employed for matching the $T_{g_{in}}$ calculated in the superheating section with the T_{g1} specified in the initial conditions.

Since the model does not allow the calculation of fractional passes and since the scheme for the calculation of superheater passes will not allow inclusion of a pass which would require a gas inlet temperature higher than that specified in the initial conditions, the final gas inlet temperature calculated for the WHRU will generally be lower than that initially specified. In order to match this superheater gas inlet temperature with that specified initially, the heat exchanger gas outlet temperature is allowed to rise. Each time the gas outlet temperature is increased, the entire waste heat recovery unit calculation is performed again, and the calculated superheater gas inlet temperature is compared with the gas turbine exhaust temperature. When a match is achieved the design is fixed.

G. OFF-DESIGN CALCULATIONS

Once a particular design has been selected the designer must test that design at several off-design points. A design will define the following WHRU characteristics:

- Dimensions (length, width, height)
- Operating pressure
- Superheater outlet temperature
- Fin-tube configuration.

The off-design calculation requires that the selected WHRU design performance be predicted for a gas inlet temperature and flow rate different from that which was used to produce the selected design. The design model can be used in an iterative fashion to make this calculation. All model calculations are made as prescribed in the previous sections, with the exception of the pinch point calculations which are not performed.

The off-design procedure requires that the designer fix the WHRU frontal dimensions, operating pressure, fin-tube configuration and minimum gas outlet temperature. A design is then produced for a gas inlet temperature and flow rate at an off-design point. This design is checked to determine whether it conforms to the height dimension of the WHRU designed at the gas conditions of the off-design point. If the height dimension is not matched then the number of WHRU passes must be adjusted until a match with the design-point WHRU is achieved. The number of WHRU passes

may be altered by either adjusting the WHRU gas outlet temperature or the superheater outlet steam temperature. The effect of either of these adjustments is to change the steam flow rate and the heat transfer rate. It would be possible to adjust the steam flow rate and allow the superheater steam outlet temperature to remain fixed. However, for the method of this model, the computation time required for this means of control would be large. The actual procedure used produces designs relatively quickly which closely approximate the results which would be obtained by a fine control on steam flow. Each time the superheater steam outlet or gas outlet temperature is adjusted, a new design is produced. This procedure is continued until a design is produced for which the height (number of passes) equals that of the design point WHRU. When the WHRU height at the off-design gas conditions is equal to that of the design point WHRU, the gas inlet temperature is matched with the gas inlet temperature specified for the off-design point, using the procedure described in Section E.

H. COGAS SYSTEM OUTPUT MODEL

The COGAS system output model calculates performance parameters for the combined steam and gas turbine system for a specified gas turbine input power. The WHRU model provides a steam flow rate, pressure, and temperature for a specified set of gas turbine exhaust gas conditions which correspond to a particular gas turbine horsepower setting.

This WHRU output is applied in a simple Rankine cycle to calculate the steam-side power output. The gas-side pressure drop calculated in the WHRU model is used to arrive at a revised gas turbine horsepower. By combining these two power outputs, a COGAS system power can be calculated. Other performance indicators such as specific fuel consumption, thermal efficiency and steam turbine share of the load are also calculated in the COGAS system output model.

1. Rankine Cycle

The following conditions are assumed for the Rankine cycle calculations:

a. No line losses

b. Steam turbine efficiency = η_{st} = 0.85

c. Condenser pressure = 2.0 psia (4 in Hg)

d. Feedwater heater pressure = 15 psia

e. Feedwater temperature = 200 F

f. Pumping power required is neglected

g. Fuel LHV = 18400 Btu/lbm

The following input conditions are received from the WHRU model: steam turbine inlet pressure (P_1), steam turbine inlet temperature (T_1), steam flow rate ($\dot{m}_f$), gas turbine exhaust pressure drop (ΔP_{gas}). From P_1 and T_1 the turbine inlet enthalpy (h_1) and inlet entropy (s_1) can be found. The turbine exhaust steam quality, assuming isentropic expansion, x_{2s}, is calculated from

$$X_{2s} = \frac{S_1 - S_f}{S_{fg}} ,$$

where

s_f = entropy of saturated water

s_{fg} = entropy increment for evaporation.

The steam turbine exhaust enthalpy assuming isentropic expansion, h_{2s}, may now be calculated from

$$h_{2s} = h_f + X_{2s} h_{fg}$$

where

h_f = enthalpy of saturated water

h_{fg} = enthalpy increment for evaporation.

The isentropic turbine work is

$$W_{ts} = h_1 - h_{2s} ,$$

and the actual steam turbine work is calculated from

$$W_t = \eta_{st} W_{ts} .$$

The actual turbine exhaust enthalpy and quality are

$$h_2 = h_1 - W_t$$

and

$$X_2 = \frac{h_2 - h_{2f}}{h_{fg}} .$$

In this model it is assumed that heating steam for the feed-water heater is provided, via a reducing station, from the main steam line. The fraction of the steam mass flow rate from the WHRU required for the feedwater heater is

$$m = \frac{h_{fw} - h_2}{h_1 - h_2}$$

where

h_{fw} = enthalpy of the feedwater

h_2 = enthalpy of the condensate at feedwater heater pressure.

Therefore, the steam turbine power output is

$$P_{st} = (1 - m)\ \dot{m}_f\ W_t .$$

2. <u>Gas Turbine Performance Calculations</u>

The original gas turbine horsepower, exhaust gas flow rate, and exhaust gas temperature inputs to the WHRU model were hand-calculated using figure 4 of Ref. 11 and figures 1, 6, and 8 of Ref. 10. The assumptions used to calculate the WHRU model inputs were:

Ambient temperature = 100 F

Ambient pressure = 14.696 psia

Humidity = 0.0

Fuel LHV = 18400 Btu/lbm

Inlet loss = 4.0 in. H_2O

Exhaust loss = 6.0 in. H_2O

In the COGAS system output model, the gas turbine horsepower correction factor for the gas-side pressure drop in the WHRU (BHP for 6" loss/BHP for WHRU loss) is found by solving

$$C_{bhp} = 1.0125 + 0.002125\ \Delta P_{gas} \ ,$$

where C_{bhp} = *BHP for 6" loss/BHP for WHRU loss.* This relationship was found by extending the duct loss relationship of fig. 7, Ref. 11 linearly from the point of 6 in. H_2O exhaust duct loss already assumed. The final gas turbine horsepower is

$$P_{gt} = \frac{P^*_{gt}}{C_{bhp}}$$

where P^*_{gt} is the input gas turbine horsepower. The total COGAS system horsepower, P_{tot}, is found by adding the steam turbine and final gas turbine horsepowers.

In order to calculate the gas turbine specific fuel consumption fig. 4 of Ref. 11 is entered with the final

gas turbine horsepower, and the s.f.c. is read from the propeller law curve superimposed on that figure. The s.f.c. correction factor for exhaust loss in the WHRU, C_{sfc}, is found in the same manner as C_{bhp} from fig. 6 of Ref. 11 where

$$C_{sfc} = (\text{s.f.c. for total exhaust } \Delta P)/(\text{s.f.c. for 6" exhaust } \Delta P)$$

and the gas turbine specific fuel consumption is

$$\text{s.f.c.}_{gt} = C_{sfc}\ \text{sfc}_{6\text{ in. loss}}$$

The specific fuel consumption for the combined system is calculated by first finding the fuel consumption rate of the gas turbine

$$\dot{m}_{fuel} = \text{s.f.c.}_{gt}\ P_{gt}\ .$$

The COGAS system s.f.c. is then calculated from

$$\text{s.f.c.}_{COGAS} = \frac{\dot{m}_{fuel}}{P_{tot}}$$

To allow the direct comparison of the COGAS system with the all gas turbine system the specific fuel consumption of the gas turbine at the new, higher COGAS system power, s.f.c.^{*}_{gt}, is calculated in the same manner as s.f.c._{gt}.

The thermal efficiencies for the gas turbine at input power, the COGAS system, and the gas turbine at COGAS system power are calculated from the relationship

$$\eta_{th} = \frac{2545}{\text{s.f.c. LHV}} .$$

Additionally, the steam turbine share of the load is calculated from P_{st}/P_{tot}.

III. RESULTS AND CONCLUSIONS

A. BACKGROUND

The foregoing model was applied in a computer simulation program written in FORTRAN IV for the IBM 360-67 computer. A listing of this program appears in Appendix A. Additionally a set of supporting programs was written for water, steam, and air properties. A listing of this set of programs appears in Appendix B.

In order to test the model and develop an understanding of the behavior of the WHRU, a set of designs were produced for a variety of initial conditions. These designs were then reviewed, and an analysis of the model behavior was performed. After completion of the model analysis, several of the designs were selected for observation at off-design conditions. The off-design simulations were produced for gas turbine input powers corresponding to ship speeds of 9, 16, and 20 knots, which represents the entire range of gas turbine input powers considered in this thesis. Finally, two designs were selected for detailed testing at off-design conditions. These latter two designs were tested at gas turbine input horsepowers corresponding to speeds of 9 to 20 knots, at one knot increments.

B. DESIGN VARIABLES

The following set of design variables was selected to produce the basic set of designs.

1. WHRU operating pressure: Three WHRU operating pressures of 400, 600, and 800 psia were selected for design production.

2. WHRU geometric scale: In order to test the model response to a range of fin-tube sizes, designs were produced for the basic fin-tube configuration described in the geometry subsection at 1.0, 0.75, and 0.50 scale.

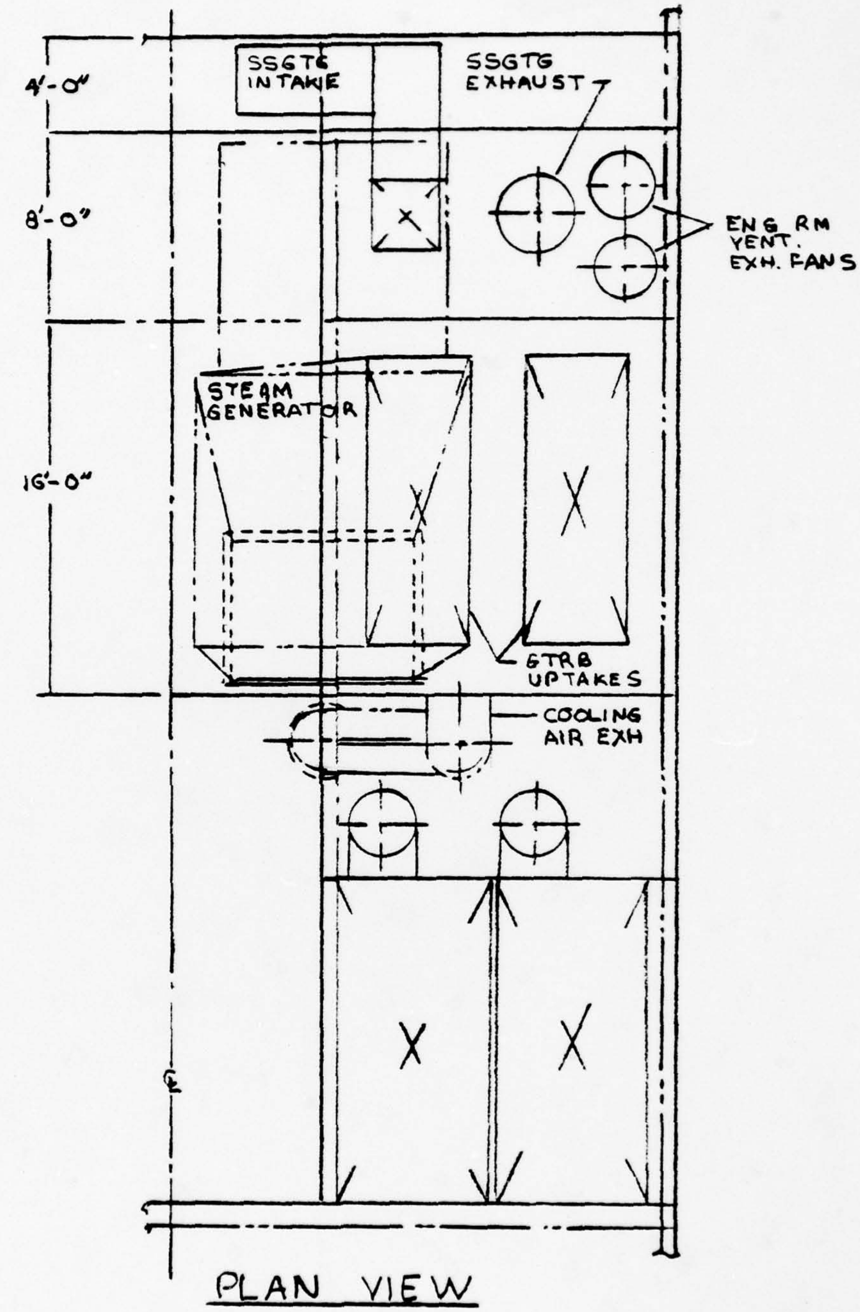
3. Frontal dimensions: The approximate WHRU space constraints for a DD-963-type engineroom are shown in figures 7, 8 and 9. Consistent with these constraints, frontal dimensions of 12' x 12' and 12' x 15' were selected for the initial design set.

4. Gas turbine input power: The gas turbine input horsepower determines the input gas conditions, temperature and flow rate, for the WHRU. Since the most advantageous use of the COGAS system was assumed to be for "cruise" speed conditions, the range of gas turbine input horsepower considered corresponds to the gas turbine power required for a ship speed range of 9 to 20 knots, with the gas turbine operating alone. The three gas turbine input powers selected for the production of WHRU designs are shown in Table I.

Gas Turbine Input Powers

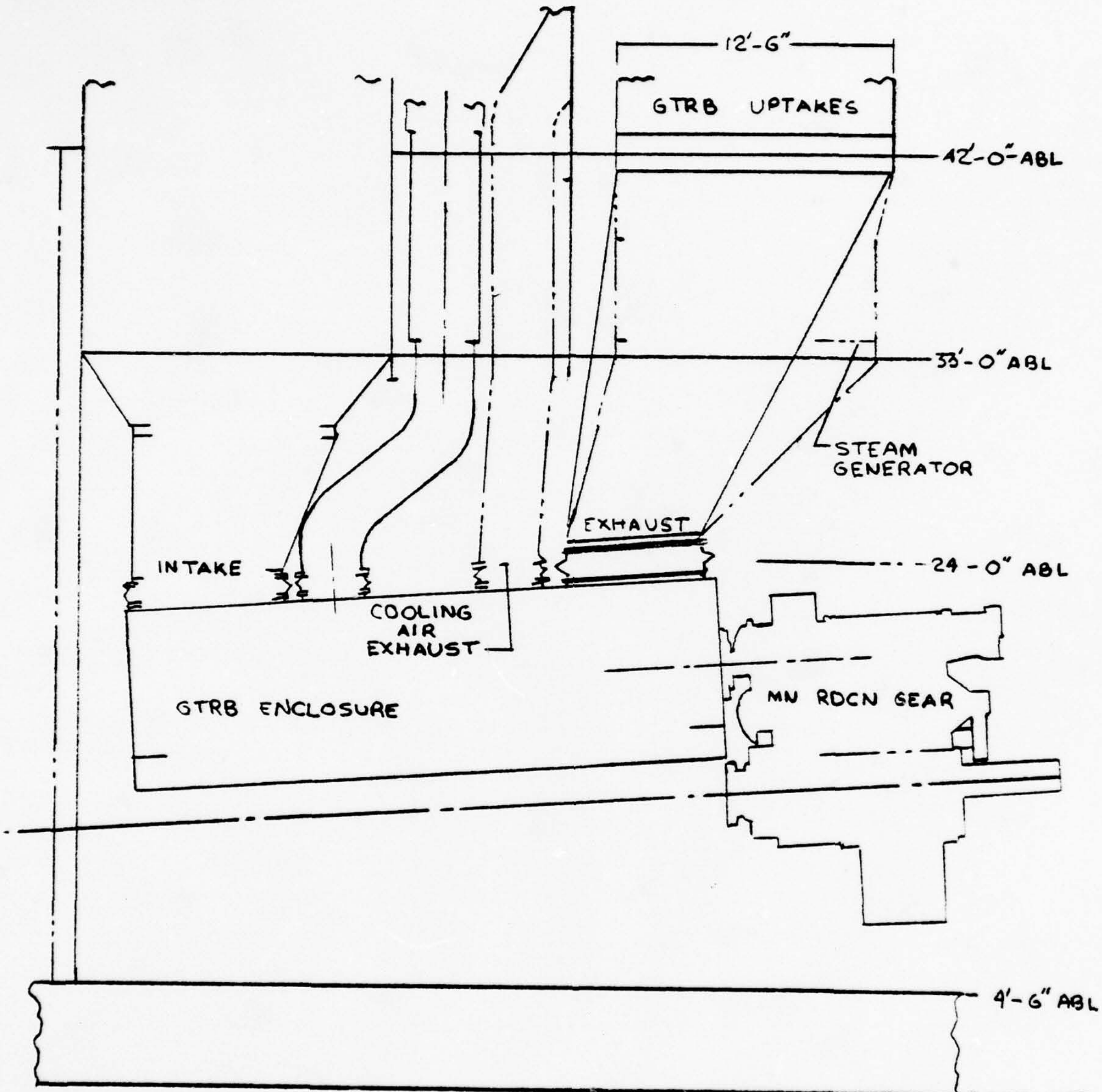
GTHP	Approx. Speed (kts)	Temperature (F)	Flow Rate (lbm/hr)
16421	20	849	407589
8526	16	742	328641
1684	9	689	159731

Table I



ENGINEROOM

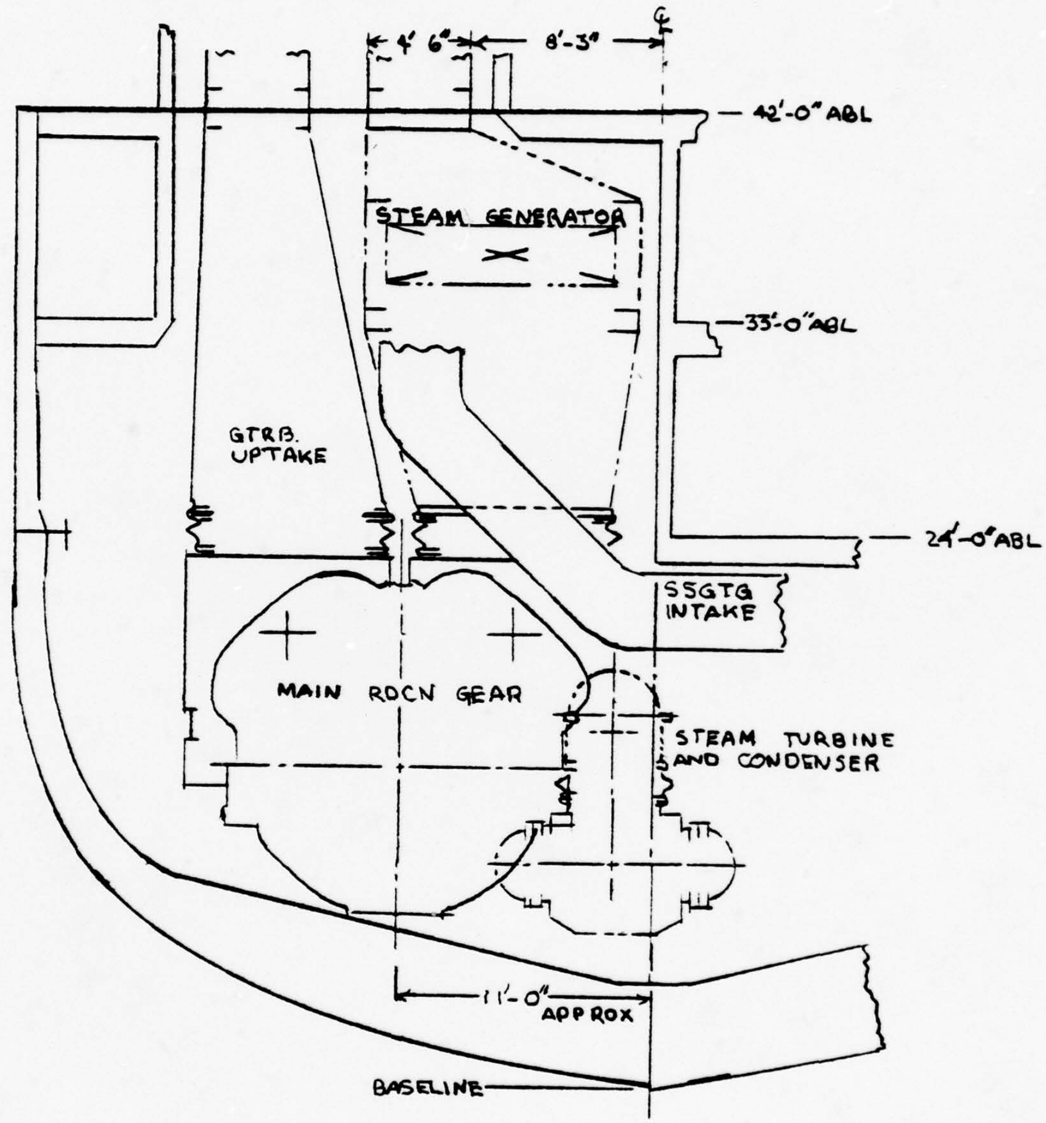
FIGURE 7



ELEVATION

ENGINEROOM

FIGURE 8



SECTION

ENGINEROOM

FIGURE 9

5. WHRU gas outlet temperature: The WHRU gas outlet temperature is fixed at 400 F. Reference 3 states that the principal cause of "hot" corrosion in the WHRU would be due to the formation of H_2SO_4 from an expected concentration of SO_3 of up to 50 parts per million. Reference 13 states that dew point condensation of vapor in the exhaust gas becomes a problem for corrosion if the stack temperature is depressed below 250 F. Therefore, a minimum average gas outlet temperature of 400 F is considered to be reasonably safe from the aspect of gas-side corrosion prevention. It should be further noted that the outlet gas temperature calculated by the program is an average temperature, based on the heat release from the gas. Therefore, the actual temperature of the gas in the stack will be cooler than 400 F in some locations due to the non-uniform distribution of the gas temperature as it leaves the WHRU. It should further be noted that, although this temperature is a fixed design variable for design production, it will vary somewhat from 400 F in response to the program calculations for setting the minimum pinch point and for matching the gas inlet temperature with that specified in the initial conditions.

6. Superheater outlet steam temperature: The target WHRU superheater outlet steam temperature is 650 F. This temperature will also vary somewhat in response to steam flow rate changes brought about by the program calculations to match

the gas inlet temperature with that specified in the initial conditions.

7. WHRU water inlet temperature: The WHRU water inlet temperature is fixed at 200 F.

8. The other major COGAS system parameters are fixed as follows:

Condenser pressure: 4 in. Hg

Steam turbine efficiency: 0.85

Feedwater heater pressure: 15.0 psia

Fuel LHV: 18400 Btu/lbm.

C. THE DESIGN SET

A set of 54 designs was produced for the combination of design variables just discussed. The array of design variable combinations is described in Table II. The summary computer output pages for the results of each design run are presented in Appendix C.

As discussed in Section A, the purposes for producing this design set were to test the model and to promote an understanding of the likely behavior of a WHRU for a range of conditions. To this end, the following set of output variables was considered.

1. WHRU output

   a. height (number of passes)

   b. gas inlet temperature

   c. gas outlet temperature

   d. steam flow rate

WHRU DESIGN COMBINATIONS AND DESIGN RUN INDEX

		Front: 12' X 12'			Front: 12' X 15'		
GTHP	Pressure	Scale=1.0	Scale=0.75	Scale=0.50	Scale=1.0	Scale=0.75	Scale=0.50
	400	run #19	run #22	run #25	run #46	run #49	run #52
16421	600	run #10	run #13	run #16	run #37	run #40	run #43
	800	run #1	run #4	run #7	run #28	run #31	run #34
	400	run #20	run #23	run #26	run #47	run #50	run #53
8526	600	run #11	run #14	run #17	run #38	run #41	run #44
	800	run #2	run #5	run #8	run #29	run #32	run #35
	400	run #21	run #24	run #27	run #48	run #51	run #54
1684	600	run #12	run #15	run #18	run #39	run #42	run #45
	800	run #3	run #6	run #9	run #30	run #33	run #36

TABLE II

e. gas side pressure drop

f. pinch point temperature difference

g. heat transfer rate

2. COGAS system output

a. gas turbine horsepower (including loss from the WHRU gas-side pressure drop)

b. steam turbine horsepower

c. COGAS system horsepower

d. steam turbine share of the load

e. specific fuel consumption

(1) s.f.c. of COGAS system

(2) s.f.c. of gas turbine at COGAS system horsepower

f. thermal efficiency

(1) η_{th} of COGAS system

(2) η_{th} of gas turbine at COGAS system horsepower

Clearly, several of these variables are related, such as s.f.c. and η_{th}, and no additional information is provided by studying all variables in a closely related group. Therefore, the following subset of output variables was selected for analysis.

1. WHRU height
2. Steam flow rate
3. Gas-side pressure drop
4. Pinch point temperature difference
5. WHRU heat transfer rate
6. WHRU gas outlet temperature

7. Steam turbine horsepower

8. COGAS system horsepower

9. COGAS specific fuel consumption

The above output variables are presented in tabular form using the format of Table II. Table II also serves as an index for the set of basic designs. Additionally, the significant trends in the variables are presented graphically. Where the trend of the results was ascertained to be the same for the two frontal dimension sets, only the values for the 12' x 12' front were presented graphically. Where clarity was better served, only one scale was plotted as representative of the trend described.

Effect of Scaling.

The only significant trends noted with respect to scaling were a decrease in WHRU height with a decrease in scale and the same trend for gas side pressure drop (see Tables III and IV). The trends are shown in figures 10 and 11.

The basic fin-tube dimensions of the model were scaled by factors of 0.75 and 0.50. For any scale with constant frontal dimensions, the total inside and outside areas remain the same. That is, for a constant length tube, the scaled inside/outside area (A_i^s/A_o^s) is proportional to the full scale areas (A_i/A_o) with the scale factor, s, as the constant of proportionality. Hence

$$A_i^s = S\,A_i \quad \text{and} \quad A_o^s = S\,A_o.$$

WHRU HEIGHT [ft]

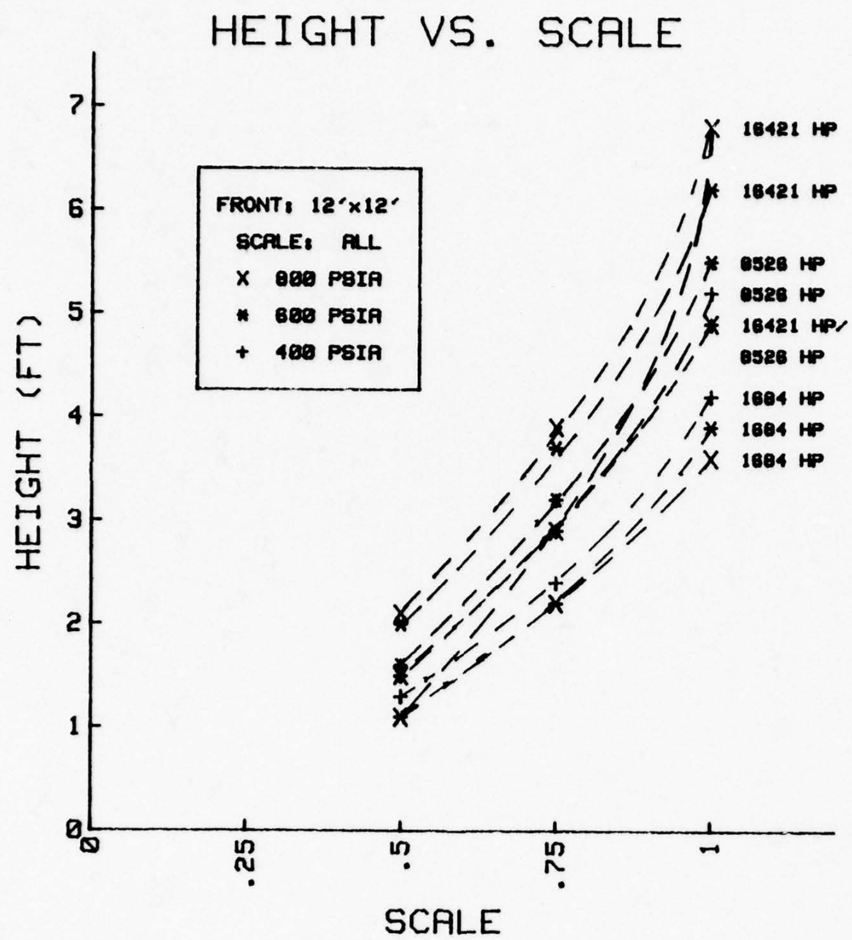
GTHP	Pressure	Front: 12' X 12' Scale=1.0	Front: 12' X 12' Scale=0.75	Front: 12' X 12' Scale=0.50	Front: 12' X 15' Scale=1.0	Front: 12' X 15' Scale=0.75	Front: 12' X 15' Scale=0.50
	400	4.9	2.9	1.5	4.6	2.7	1.5
16421	600	6.2	3.7	2.0	5.5	3.4	1.8
	800	6.8	3.9	2.1	5.9	3.7	2.0
	400	5.2	3.2	1.6	4.9	2.9	1.5
8526	600	5.5	3.2	1.6	4.9	2.9	1.5
	800	4.9	2.9	1.5	4.6	2.7	1.5
	400	4.2	2.4	1.3	3.9	2.4	1.1
1684	600	3.9	2.2	1.1	3.6	2.2	1.1
	800	3.6	2.2	1.1	3.3	2.0	1.0

TABLE III

GAS SIDE PRESSURE DROP [in H_2O]

		Front: 12' X 12'			Front: 12' X 15'		
GTHP	Pressure	Scale=1.0	Scale=0.75	Scale=0.50	Scale=1.0	Scale=0.75	Scale=0.50
	400	5.3	4.4	3.5	3.3	2.7	2.5
16421	600	6.7	5.6	4.9	4.0	3.5	3.0
	800	7.8	6.0	5.3	4.3	3.7	3.3
	400	3.8	3.2	2.7	2.4	1.9	1.6
8526	600	4.1	3.3	2.8	2.4	2.0	1.6
	800	3.7	3.1	2.5	2.4	1.9	1.7
	400	0.8	0.7	0.6	0.5	0.4	0.3
1684	600	0.8	0.6	0.5	0.5	0.4	0.3
	800	0.8	0.6	0.5	0.5	0.4	0.3

TABLE IV



HEIGHT VS. SCALE
FRONT: 12'x12'
SCALE: ALL
X 800 PSIA
* 600 PSIA
+ 400 PSIA
16421 HP
16421 HP
8526 HP
8526 HP
16421 HP/
8526 HP
1684 HP
1684 HP
1684 HP
HEIGHT (FT)
0
1
2
3
4
5
6
7
.25
.5
.75
1
SCALE

FIGURE 10

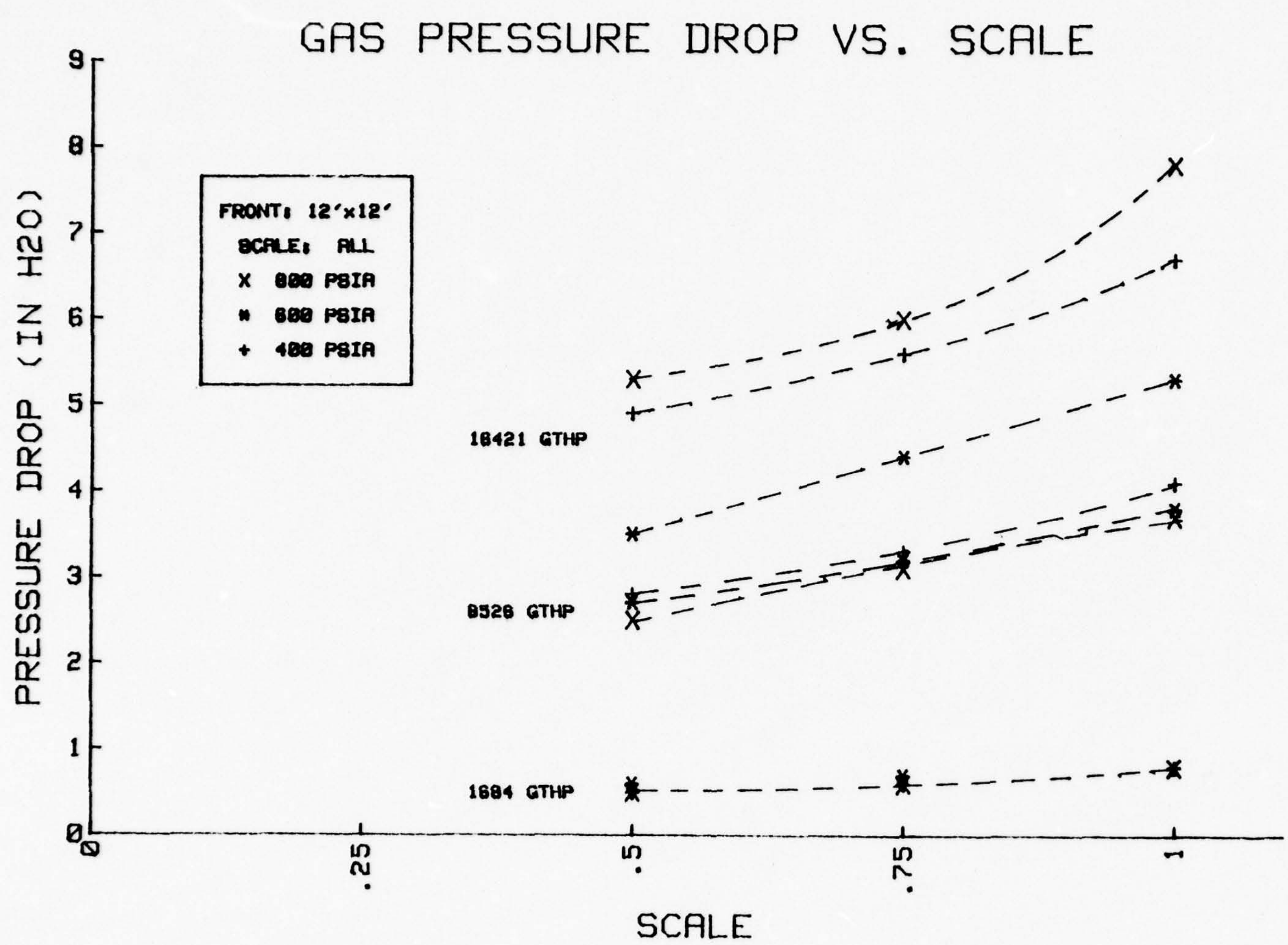

GAS PRESSURE DROP VS. SCALE
PRESSURE DROP (IN H2O)
SCALE
FRONT: 12'x12'
SCALE: ALL
X 800 PSIA
* 600 PSIA
+ 400 PSIA
18421 GTHP
8526 GTHP
1684 GTHP
0
1
2
3
4
5
6
7
8
9
.25
.5
.75
1

FIGURE 11

Since constant frontal dimensions are to be maintained, the number of tubes per row is scaled up by the scale factor, so

$$A_{ip}^{s} = \frac{N_{t/p}}{s} s A_i \quad \text{and} \quad A_{op}^{s} = \frac{N_{t/p}}{s} s A_o ,$$

where $N_{t/p}$ is the number of tubes per pass. Therefore, the scaled outside and inside areas for a pass for constant frontal dimensions are the same as the full scale areas. Now, the scaled cross-sectional area for fluid flow on the inside will be,

$$A_{ff}^{s} = \frac{\pi}{4} s^2 d_i^2 \frac{N_{t/p}}{s} = s A_{ff} .$$

So the scaled Reynolds number will be

$$R_e^s = \frac{\dot{m}_f s d_i}{s A_{ff} \mu} = \frac{\dot{m}_f d_i}{A_{ff} \mu}$$

which is equal to the Reynolds number for the unscaled geometry. It can also be shown that the outside Reynolds number remains constant with scaling. Recalling that the Dittus-Boelter correlation was used to calculate the inside heat transfer coefficient for the single phase regions and used with a multiplier for the two phase heat transfer coefficient and assuming constant fluid properties, the Nusselt number remains constant

$$N_u = 0.023\, R_e^{0.8}\, P_r^{0.4} = \text{Const.} = C\ .$$

So, the scaled inside heat transfer coefficient

$$h_f^s = \frac{K}{s\, d_i} C = \frac{C}{s}$$

increases with a decreasing scale factor. Similarly, for the scaled gas-side heat transfer coefficient,

$$h_g^s = j\, \frac{k}{s\, d_o}\, R_e\, P_r^{1/3} = \frac{C}{s}\ ,$$

an increase is seen with a decreasing scale factor. Therefore, in addition to a decrease in height attributable to a scaling down of the fin-tube dimensions, there is also an improvement in heat transfer which results in a further reduction in height by elimination of passes. This trend is supported by the results.

Recalling the relationship used to calculate the gas-side pressure drop,

$$\Delta P_g = \frac{2f\, G_{max}^2\, N_{t/r}}{\rho} \left(\frac{\mu_w}{\mu_b}\right)^{0.14}\ ,$$

it can be shown that the scaled gas-side pressure drop is inversely proportional to the scale factor,

$$\Delta P_g^s = \frac{C}{s}\ ,$$

where C is a constant based on the assumption of constant gas properties between scales. For the same number of passes, then, an increase in gas-side pressure drop could be expected. However, since the number of passes is decreased with decreasing scale, a net decrease in gas-side pressure drop was experienced (Fig. 11).

Some differences in pinch point with scale were observed in Table V, but no consistent trend could be established. It was expected that pinch point ΔT would remain fairly constant with scale for fixed pressure and input gas conditions. That result was apparent to some extent, particularly in the range of high gas temperature and low steam pressure. This finding is consistent with the manner in which the pinch point ΔT is established. That is, the program fixes an initial pinch point ΔT only when the rough pinch point ΔT is less than 25 F in the initial calculations. At the lower pressures and higher gas temperatures this mechanism would not be operative. Also, the final and initial pinch point ΔT calculations are based on the average gas temperatures at the inlet to the pass where the ΔT is calculated. Therefore, the actual pinch point may be either lower or higher than the one calculated, depending on the actual gas temperature distribution at the inlet to the pass. The pinch point ΔT will be discussed at greater length in the analysis of the effects of pressure.

PINCH POINT ΔT [F]

		Front: 12' X 12'			Front: 12' X 15'		
GTHP	Pressure	Scale=1.0	Scale=0.75	Scale=0.50	Scale=1.0	Scale=0.75	Scale=0.50
	400	71.9	71.5	71.9	64.4	64.8	62.4
16421	600	37.2	40.7	48.4	38.7	45.8	42.0
	800	32.0	32.9	36.0	32.5	36.4	30.7
	400	42.4	41.5	41.1	36.9	36.4	36.9
8526	600	27.1	37.1	36.7	32.7	31.6	31.5
	800	36.8	36.1	34.8	31.2	30.5	30.4
	400	30.1	33.6	39.9	42.6	29.9	36.2
1684	600	41.8	54.9	33.0	37.3	50.6	29.8
	800	39.6	53.0	30.9	35.0	47.7	84.2

TABLE V

Effect of Pressure.

The most important effect of pressure on the model performance arises from the calculations which establish the minimum pinch point temperature difference. As related in the model description, the minimum pinch point ΔT is set at 25 F. The WHRU outlet gas temperature is adjusted in the initial model calculations in order to ensure this minimum ΔT. The initial model calculations establish the steam flow rate from a simple energy balance involving the gas inlet and outlet temperatures (T_{g1},T_{g2}), the gas flow rate, the water inlet temperature (T_{f1}), the required steam outlet temperature (T_{f4}), and the steam pressure. Tentative interim gas temperatures for the heater inlet, T_{g3}, and boiling section inlet, T_{g2}, are also established in this calculation set. In order to establish the minimum pinch point ΔT, the model tests the interim heater gas inlet temperature against the criterion

$$T_{g3} \geq T_{f2} + 25$$

where T_{f2} is the temperature of saturated water at the pressure specified. If T_{g3} is less than T_{f2} + 25 then T_{g3} is set equal to T_{f2} + 25 and a new gas outlet temperature is calculated as follows,

$$T_{g4} = \frac{T_{g3} - \alpha T_{g1}}{1 - \alpha}$$

where

$$\alpha = \frac{h_{f2} - h_{f1}}{h_{f4} - h_{f1}} \text{ .}$$

As an aid to understanding the behavior of the model, it is useful to predict the WHRU gas inlet temperature at which this pinch point calculation becomes operative for a particular pressure. This is accomplished by establishing a "critical" heater gas inlet temperature, T^*_{g3}, for each pressure considered,

$$T^*_{g3} = T_{f\ sat} + 25 \text{ ,}$$

where $T_{f\ sat}$ is the temperature of saturated water at the pressure specified. The ratio α can also be solved for each pressure considered, based on a constant water inlet temperature of 200 F and a constant superheater outlet temperature of 650 F,

$$\alpha = \frac{h_f - h_1}{h_4 - h_1}$$

where h_f = enthalpy of saturated water at the pressure under consideration. Finally, assuming a minimum WHRU gas outlet temperature of 4-0 F the minimum WHRU gas inlet temperature at which the pinch point calculation comes into effect may be calculated as follows,

$$T^*_{g1} = \frac{T^*_{g3} - (1 - \alpha)400}{\alpha} .$$

Table VI summarizes these calculations for each of the pressures considered in the design set.

Minimum Gas Inlet Temperature for Pinch Point Calculation

Pressure (psia)	T^*_{g3} (F)	α	T^*_{g1} (F)
400	470	.219	720
600	497	.262	770
800	543	.299	878

Table VI

Now the pressure at which the pinch point calculation becomes operative for each gas turbine input power considered is predicted. The pressure for which the pinch point calculation begins to adjust gas outlet temperature is listed below for each gas turbine input power considered, in Table VII.

Pressure At Which Pinch Point Calculation Takes Effect

Gas Turbine Input Power	T_{g1} (F)	Pressure (psia)	T^*_{g1} (F)
16421	849	800	878
8526	742	600	770
1684	689	400	720

Table VII

It should be recalled that the outlet gas temperature is also adjusted by the iterative technique employed to match the model-calculated gas inlet temperature with the gas inlet temperature of the initial conditions, once the design is established. This is a relatively minor adjustment, however, and is never greater than 10 F. These adjustments to WHRU gas outlet temperature are apparent in the values of Table VIII and are displayed graphically for the 12' x 12' frontal dimentions and 0.75 scale in Fig. 12.

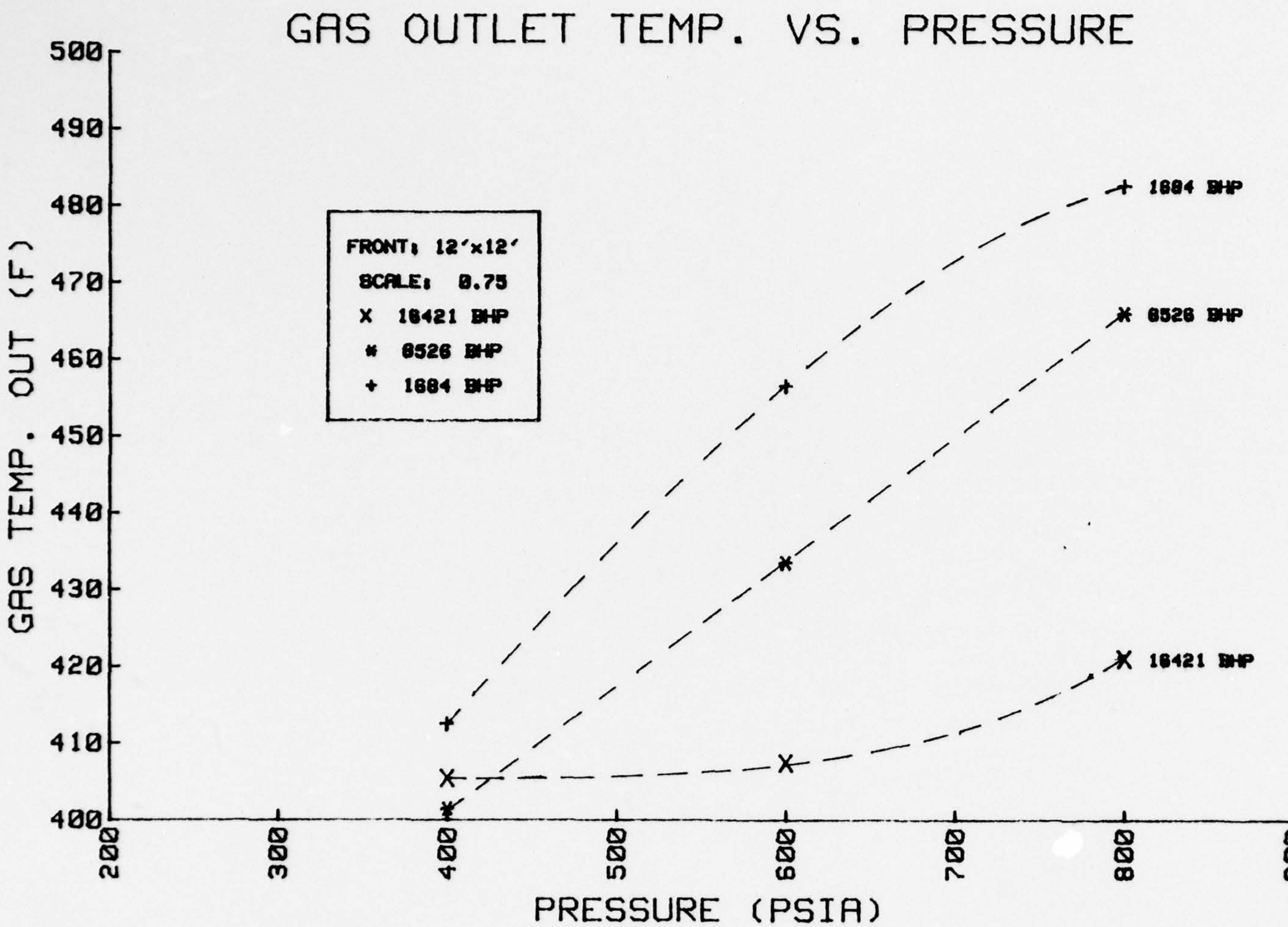
The final calculated pinch point for each of the design sets reflected the influence of the initial pinch point calculation. These results were shown in Table V and Figure 13. It is re-emphasized here that the calculated pinch point ΔT is useful only as an indicator of what the actual pinch point might be for a particular heat exchanger design. This is true because the model neglects the possibility of a gas temperature distribution across the inlet of a WHRU pass and, instead, uses the average gas temperature for calculations.

There are two other trends in the design results which emanated directly from the control exercised by the model over the pinch point ΔT and the resulting gas-fluid temperature distributions in the designs produced. These trends were apparent when the effects of pressure on WHRU height and WHRU heat transfer/steam flow rate were examined.

WHRU GAS OUTLET TEMPERATURE [F]

GTHP	Pressure	Front: 12' X 12' Scale=1.0	Front: 12' X 12' Scale=0.75	Front: 12' X 12' Scale=0.50	Front: 12' X 15' Scale=1.0	Front: 12' X 15' Scale=0.75	Front: 12' X 15' Scale=0.50
	400	405.5	405.5	409.0	400.5	405.5	405.0
16421	600	404.5	407.5	401.5	405.0	402.3	400.8
	800	415.0	421.0	414.2	419.0	415.0	414.2
	400	403.5	401.5	401.5	401.5	401.5	405.1
8526	600	430.5	433.5	434.4	431.0	435.0	436.5
	800	464.4	465.9	467.4	462.9	465.1	459.9
	400	410.5	412.6	409.6	409.6	409.6	420.0
1684	600	449.4	456.5	458.0	450.9	449.4	452.4
	800	483.0	482.5	482.5	485.5	484.0	485.5

TABLE VIII



GAS OUTLET TEMP. VS. PRESSURE
GAS TEMP. OUT (F)
500
490
480
470
460
450
440
430
420
410
400
200
300
400
500
600
700
800
900
PRESSURE (PSIA)
FRONT: 12'x12'
SCALE: 0.75
X 16421 BHP
* 6526 BHP
+ 1684 BHP
1684 BHP
6526 BHP
16421 BHP

FIGURE 12

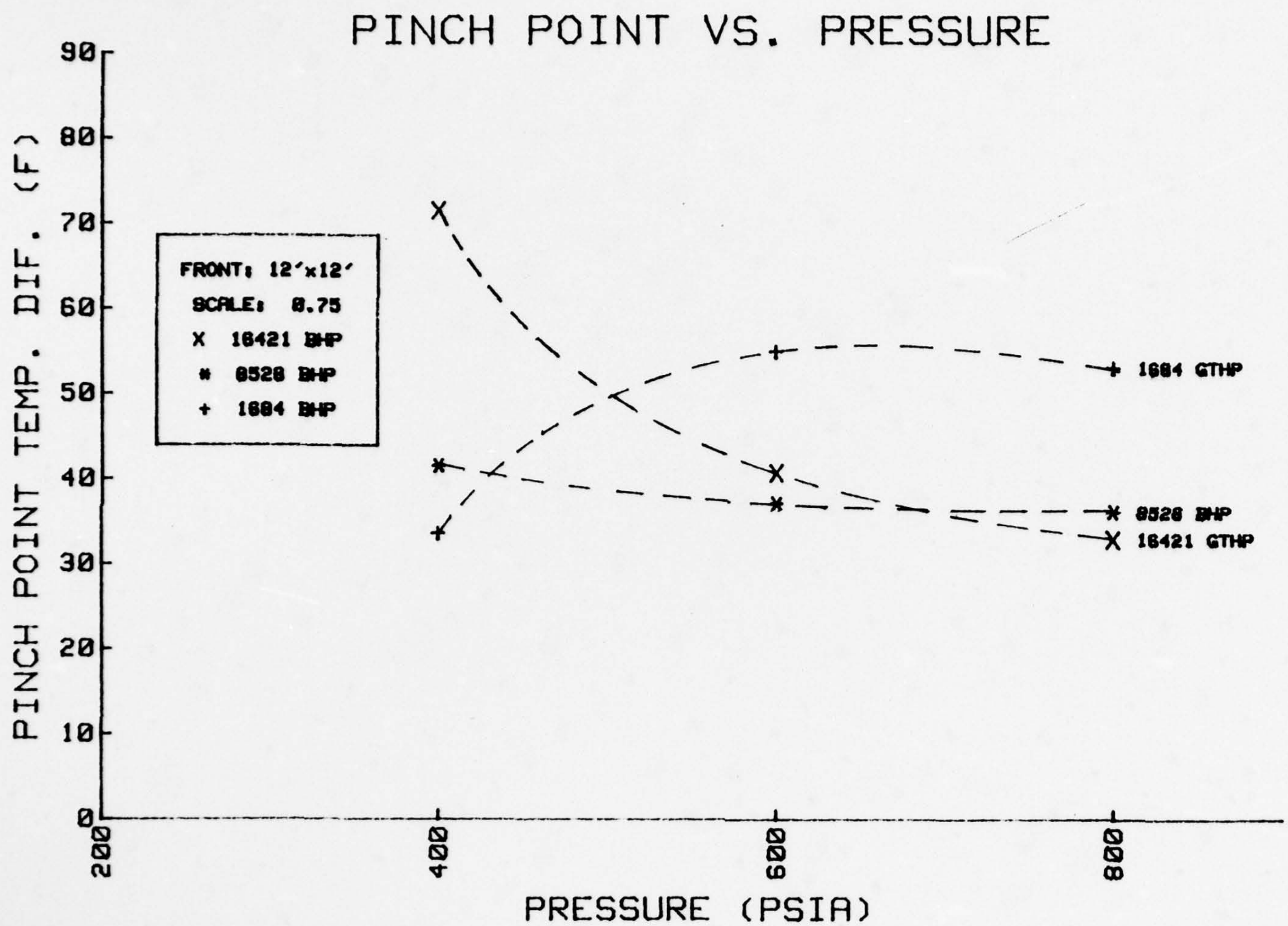

PINCH POINT VS. PRESSURE
FRONT: 12'x12'
SCALE: 0.75
X 16421 BHP
* 8528 BHP
+ 1684 BHP
1684 GTHP
8528 BHP
16421 GTHP
PINCH POINT TEMP. DIF. (F)
0
10
20
30
40
50
60
70
80
90
200
400
600
800
PRESSURE (PSIA)

FIGURE 13

The effects of pressure on WHRU heat transfer and steam flow rate are shown in Figures 14 and 15 respectively. Tables IX and X list the actual values obtained for WHRU heat transfer and steam flow rate for the designs produced. WHRU heat transfer and steam flow rate directly reflected the adjustment of the WHRU gas outlet temperature to maintain the minimum pinch point ΔT. That is, as the WHRU outlet gas temperature was raised, the heat transfer rate and steam flow decreased. The small increase shown in Figures 14 and 15 in heat transfer and steam flow rate for 16421 gas turbine input power at the 0.50 scale reflects only a minor adjustment difference in $T_{g_{out}}$ for matching $T_{g_{in}}$ between 400 psia and 600 psia.

The relationship of WHRU height to WHRU pressure is slightly more complex. Figures 16, 17, and 18 demonstrate the approximate gas-fluid temperature distribution along the total length of the WHRU for the 0.75 scale at the three pressures and input horsepowers considered. The general trend observed in these diagrams of decreasing gas-fluid temperature difference with increasing pressure is representative of all the designs produced. This decrease in gas-fluid temperature difference, taken by itself, would produce larger heat exchangers with increasing pressure. This trend may be observed for the 12' x 12' front at the high gas turbine input horsepower in Figure 19. At the medium and low gas turbine horsepowers, however, the WHRU

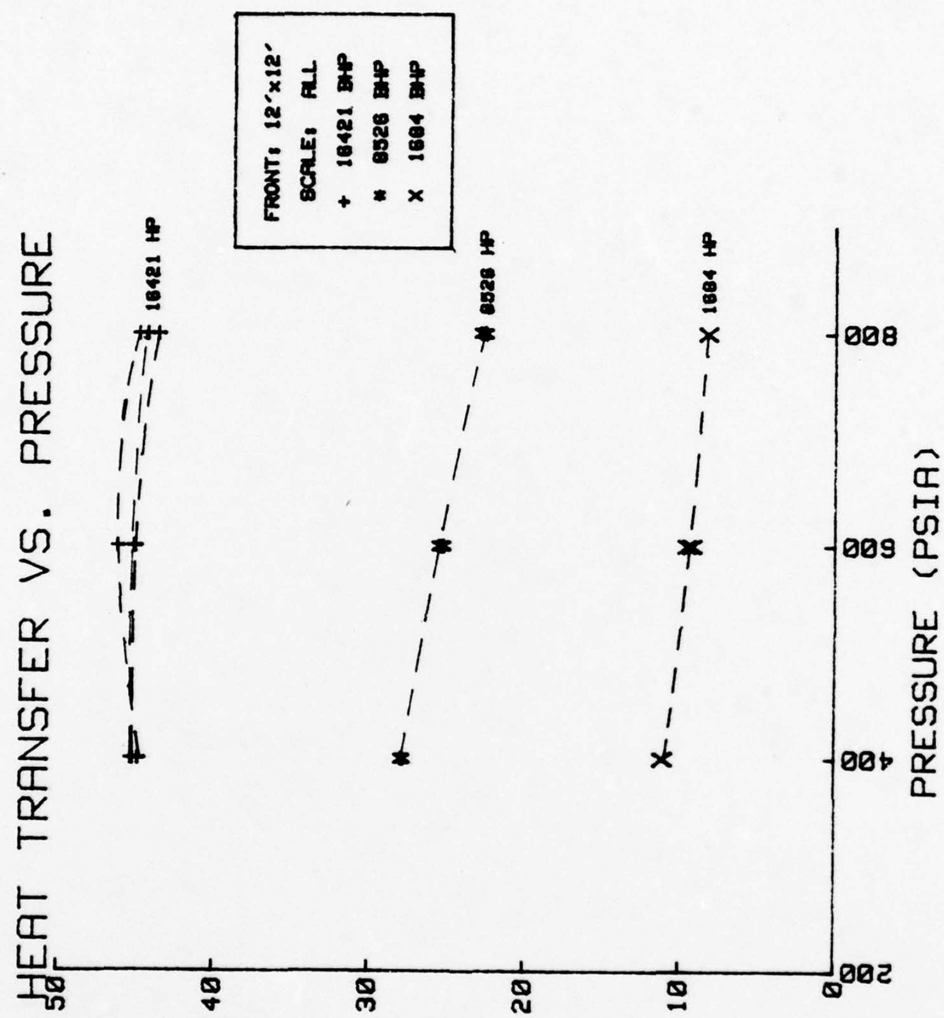

HEAT TRANSFER VS. PRESSURE
HEAT TRANSFER (BTU/HR X 10E-6)
PRESSURE (PSIA)
0
10
20
30
40
50
200
400
600
800
FRONT: 12'x12'
SCALE: ALL
+ 16421 BHP
* 8526 BHP
X 1684 BHP
16421 HP
8526 HP
1684 HP

FIGURE 14

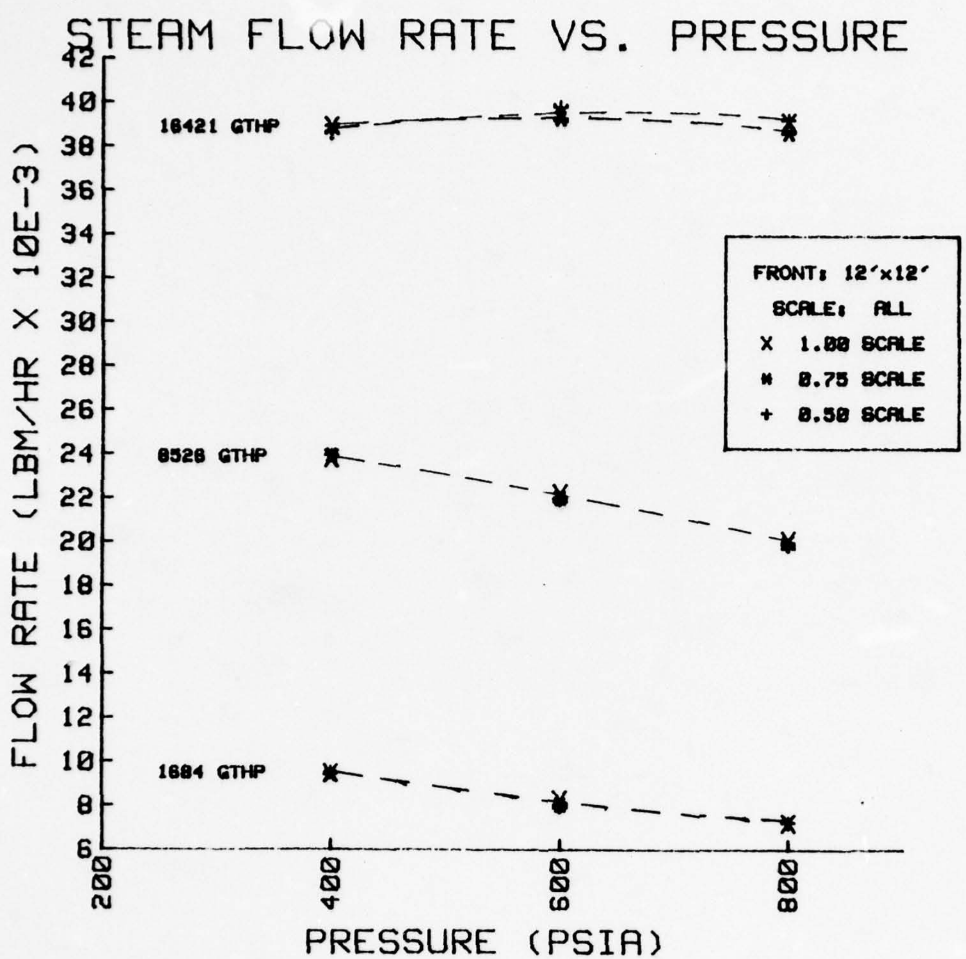

STEAM FLOW RATE VS. PRESSURE
FLOW RATE (LBM/HR X 10E-3)
PRESSURE (PSIA)
16421 GTHP
6526 GTHP
1684 GTHP
FRONT: 12'x12'
SCALE: ALL
X 1.00 SCALE
* 0.75 SCALE
+ 0.50 SCALE
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
200
400
600
800

FIGURE 15

WHRU HEAT TRANSFER RATE [Btu/hr]

		Front: 12' X 12'			Front: 12' X 15'		
GTHP	Pressure	Scale=1.0	Scale=0.75	Scale=0.50	Scale=1.0	Scale=0.75	Scale=0.50
	400	45283138	45130292	44773652	45588830	45211810	45221999
16421	600	45079343	44987636	46118695	45221999	45680537	45741675
	800	44223406	43540695	44763462	43836197	44304924	44518908
	400	27753732	27745516	27876973	27885189	27959133	27482604
8526	600	25486109	25280709	25173901	25527190	25198549	25009580
	800	22815901	22569421	22462461	22807685	22635149	23160974
	400	11073352	11017446	11125264	11137244	11133251	10697984
1684	600	9527954	9240438	9160573	9464062	9523961	9396176
	800	8170241	8226146	8194200	8110341	8174234	8126315

TABLE IX

STEAM FLOW RATE [lbm/hr]

GTHP	Pressure	Front: 12' X 12' Scale=1.0	Front: 12' X 12' Scale=0.75	Front: 12' X 12' Scale=0.50	Front: 12' X 15' Scale=1.0	Front: 12' X 15' Scale=0.75	Front: 12' X 15' Scale=0.50
	400	38942	38942	38643	39369	38942	38086
16421	600	39499	39239	39758	39455	39693	39818
	800	39124	38597	39189	38770	39124	39189
	400	23807	23945	23945	23945	23945	23698
8526	600	22207	21997	21964	22174	21894	21789
	800	20106	19999	19892	20212	20052	20426
	400	9494	9425	9526	9524	9524	9176
1684	600	8286	8044	7992	8235	8286	8184
	800	7236	7253	7253	7149	7201	7149

TABLE X

TEMPERATURE DISTRIBUTION DIAGRAMS

SCALE: 0.75
FRONT: 12'X12'
GTHP: 16421

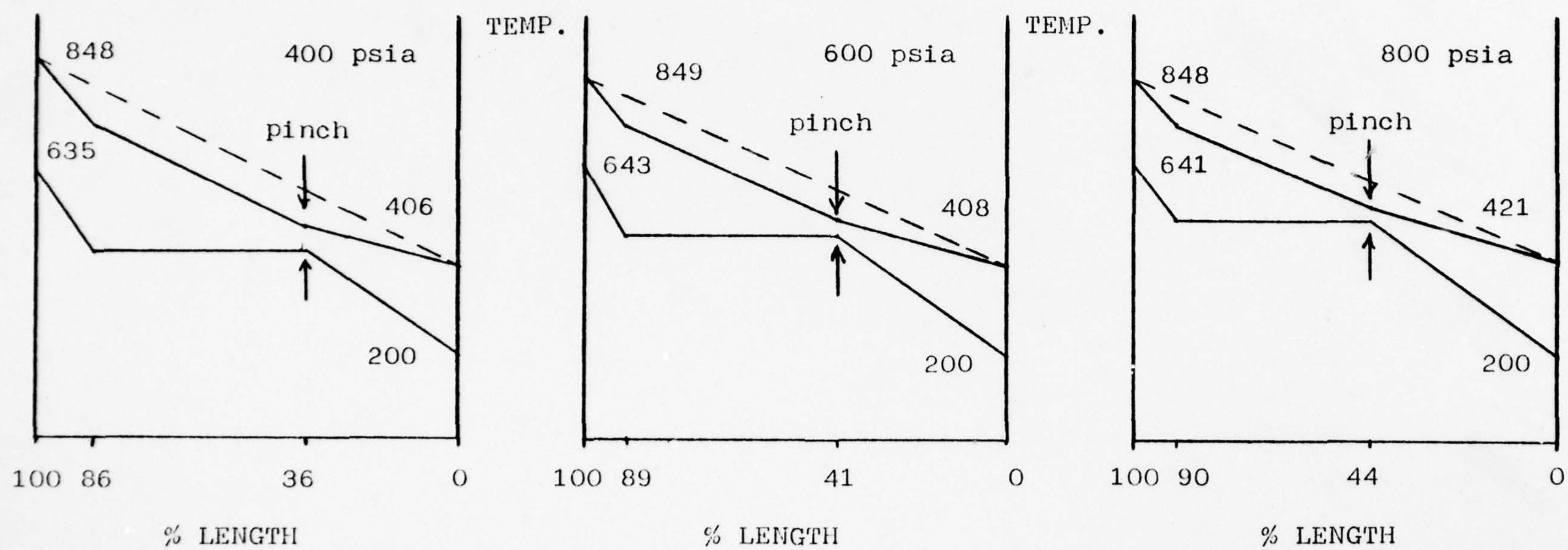


FIGURE 16

AD-A078 154 NAVAL POSTGRADUATE SCHOOL MONTEREY CA F/G 13/10
WASTE HEAT RECOVERY UNIT DESIGN FOR GAS TURBINE PROPULSION SYST--ETC(U)
SEP 79 R M COMBS

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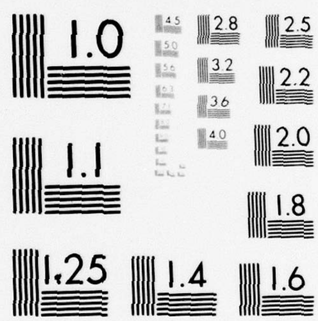


MICROCOPY RESOLUTION TEST CHART

TEMPERATURE DISTRIBUTION DIAGRAMS

SCALE: 0.75
FRCNT: 12'X12'
GTHP: 8526

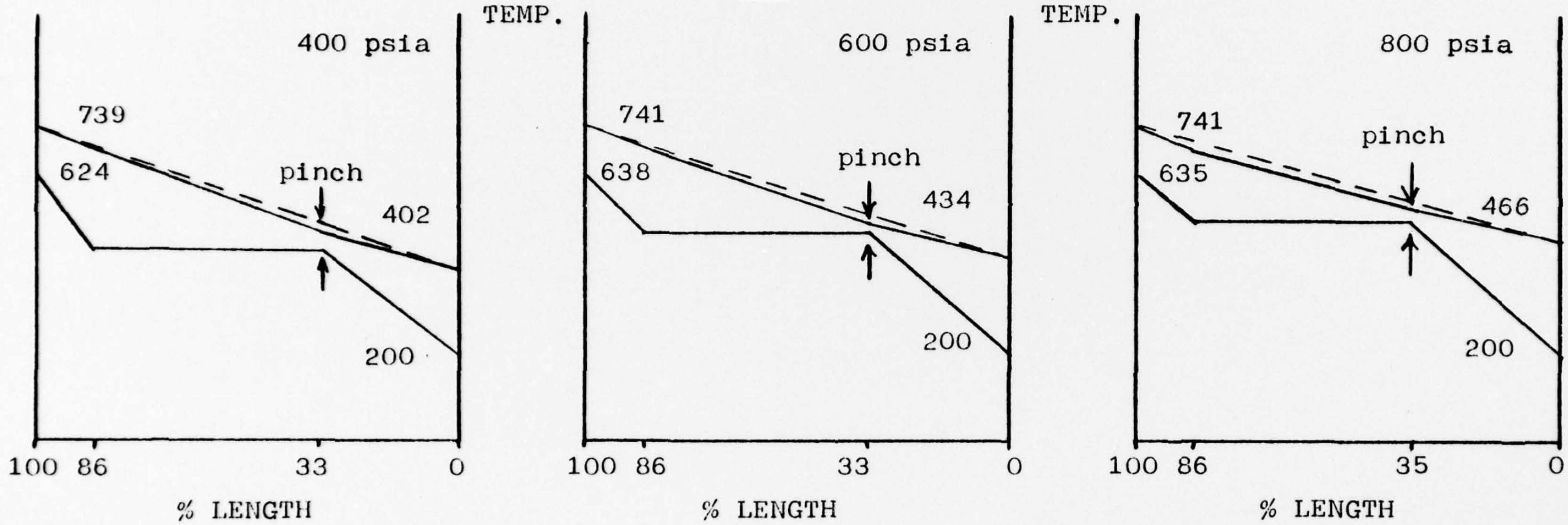


FIGURE 17

TEMPERATURE DISTRIBUTION DIAGRAMS

SCALE: 0.75
FRONT: 12'X12'
GTHP: 1684

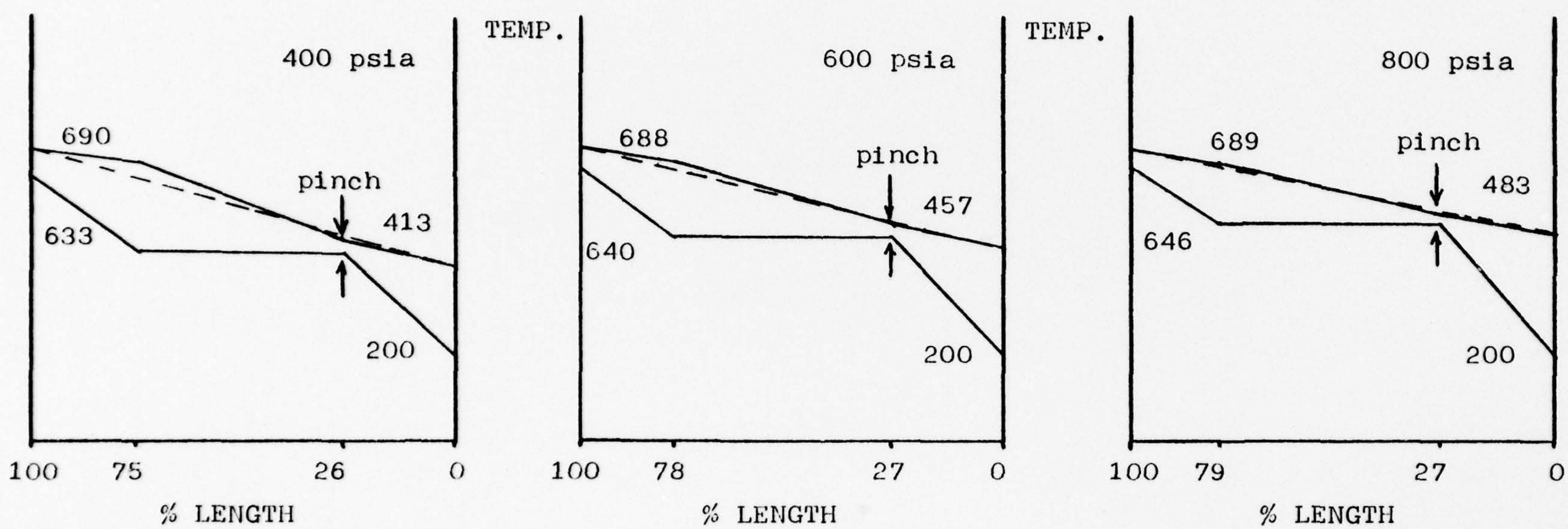


FIGURE 18

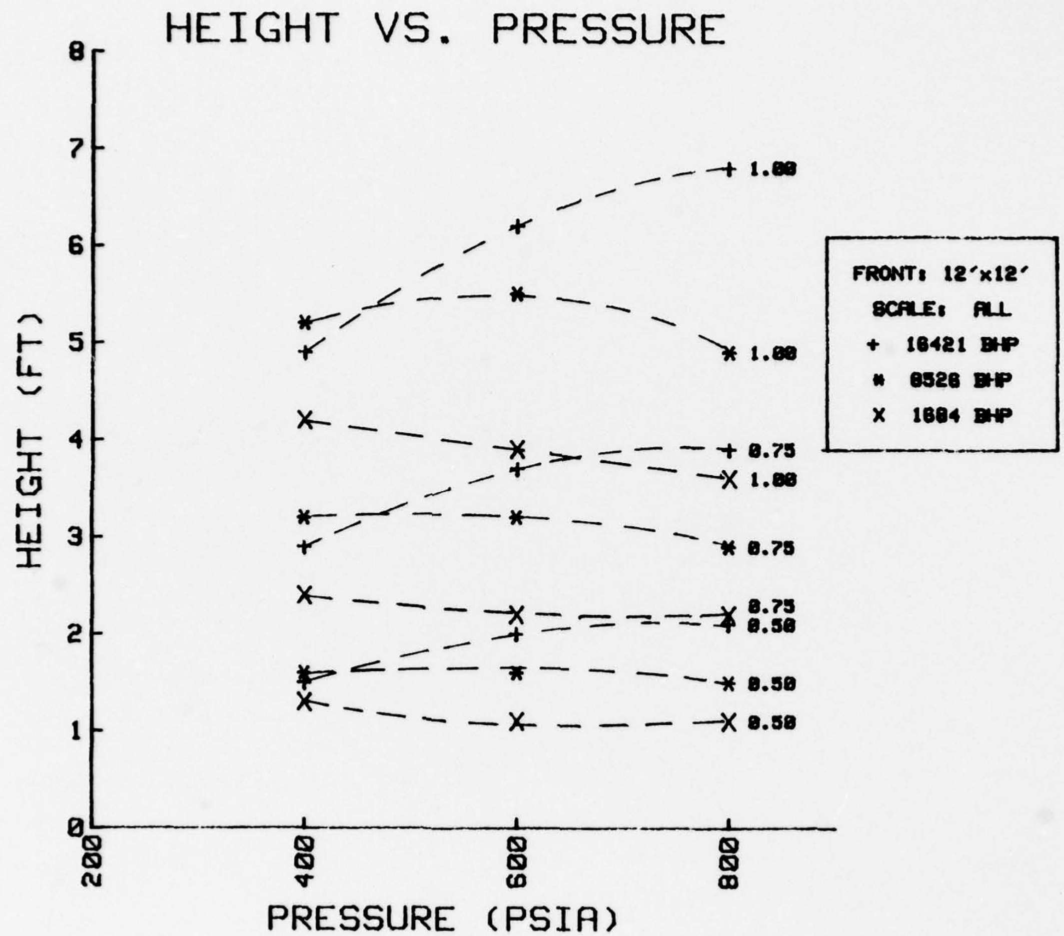

HEIGHT VS. PRESSURE
HEIGHT (FT)
PRESSURE (PSIA)
0
1
2
3
4
5
6
7
8
200
400
600
800
1.00
1.00
0.75
1.00
0.75
0.75
0.50
0.50
0.50
FRONT: 12'x12'
SCALE: ALL
+ 16421 BHP
* 8526 BHP
X 1604 BHP

FIGURE 19

height remained fairly constant or actually decreased with increasing pressure. This trend is explained by the decreasing heat transfer rate with increasing pressure attributable to the pinch point calculation adjustment to WHRU gas outlet temperature shown in Figure 12.

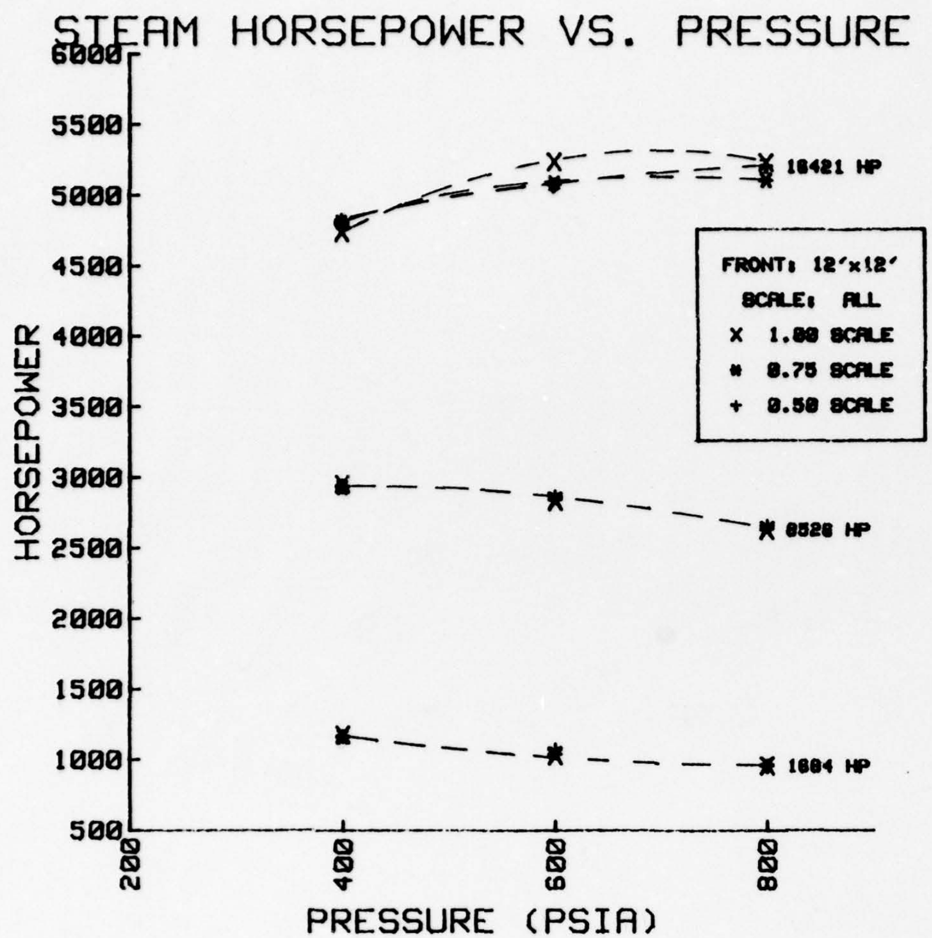
The design set results for steam turbine horsepower output are given in Table XI. These results are presented graphically for the 12' x 12' front in Figure 20. Two separate trends were identified. The steam turbine horsepower demonstrated an overall increase with increasing pressure for the high gas turbine input horsepower. Although there is a small net decrease in WHRU heat transfer rate with increasing pressure at the high gas turbine input power, the steam is rejected to the condenser at a lower quality for the higher pressures. Therefore, there is less heat rejection in the condenser for higher pressures. This better performance of the high pressure systems in the Rankine cycle more than compensates for the small decrease in WHRU output at these pressures. For the medium and low gas turbine input powers the trend of decreasing WHRU output with increasing pressure (Fig. 20) was dominant in the Rankine cycle also, producing systems of decreasing steam turbine horsepower with increasing pressure.

The design set results for the COGAS system combined horsepower are given in Table XII. The results are displayed graphically in Figure 21 for the 12' x 12' front. It is

STEAM TURBINE HORSEPOWER

		Front: 12' X 12'			Front: 12' X 15'		
GTHP	Pressure	Scale=1.0	Scale=0.75	Scale=0.50	Scale=1.0	Scale=0.75	Scale=0.50
	400	4822	4805	4733	4849	4822	4881
16421	600	5072	5081	5232	5099	5168	5154
	800	5205	5100	5227	5133	5195	5211
	400	2943	2931	2954	2957	2965	2914
8526	600	2862	2838	2828	2861	2832	2814
	800	2656	2629	2623	2670	2641	2707
	400	1171	1161	1177	1184	1181	1134
1684	600	1071	1040	1028	1062	1072	1055
	800	955	962	954	949	956	948

TABLE XI



STEAM HORSEPOWER VS. PRESSURE
HORSEPOWER
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
PRESSURE (PSIA)
200
400
600
800
10421 HP
8526 HP
1684 HP
FRONT: 12'x12'
SCALE: ALL
X 1.00 SCALE
* 0.75 SCALE
+ 0.50 SCALE

FIGURE 20

COGAS SYSTEM HORSEPOWER

GTHP	Pressure	Front: 12' X 12' Scale=1.0	Front: 12' X 12' Scale=0.75	Front: 12' X 12' Scale=0.50	Front: 12' X 15' Scale=1.0	Front: 12' X 15' Scale=0.75	Front: 12' X 15' Scale=0.50
	400	20861	20874	20831	20956	20949	20974
16421	600	21066	21112	21286	21181	21269	21272
	800	21162	21116	21267	21205	21287	21318
	400	11297	11296	11328	11336	11351	11306
8526	600	11211	11201	11201	11239	11218	11205
	800	11013	10996	10999	11049	11029	11098
	400	2832	2822	2839	2846	2843	2796
1684	600	2733	2701	2690	2724	2734	2717
	800	2616	2623	2616	2611	2618	2610

TABLE XII

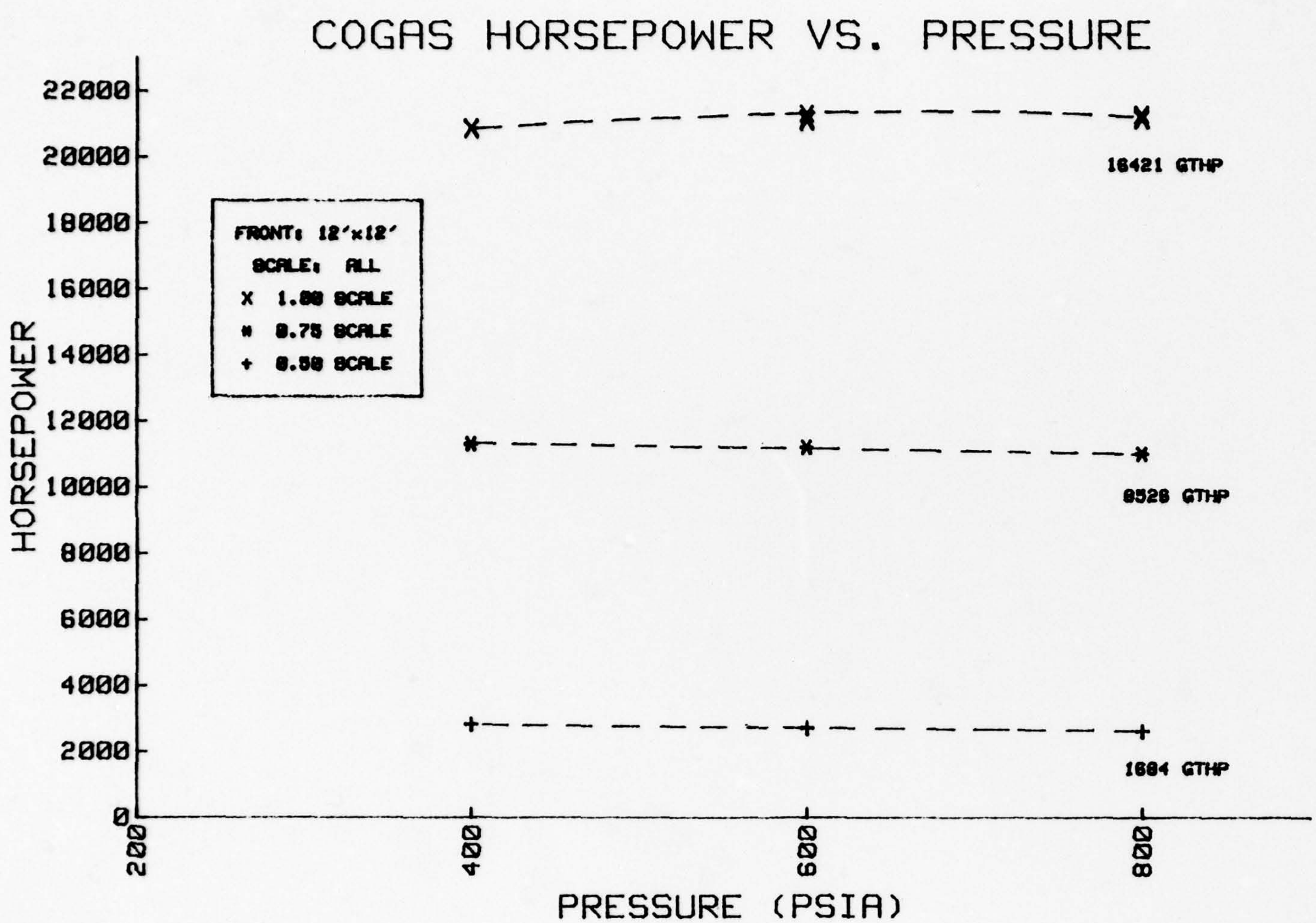

COGAS HORSEPOWER VS. PRESSURE
HORSEPOWER
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
200
400
600
800
PRESSURE (PSIA)
FRONT: 12'×12'
SCALE: ALL
X 1.00 SCALE
* 0.75 SCALE
+ 0.50 SCALE
16421 GTHP
8528 GTHP
1684 GTHP

FIGURE 21

apparent that the system horsepower output trend followed that for steam turbine horsepower output. This was the expected result. This trend is modified only slightly by additional gas turbine horsepower losses due to a changing gas-side pressure drop across the WHRU.

Finally, the system specific fuel consumption followed closely the results for steam turbine horsepower output. That is, slightly better systems were observed at lower pressures for the medium and low gas turbine input powers and a slightly better system was produced at higher pressures for the high gas turbine input horsepower. These trends are shown in Figure 22 and Table XIII.

Effect of Gas Turbine Input Power.

An increase in WHRU height with increasing gas turbine input power was noted in the results for the design set produced (see Fig. 23 and Table III). This increase in WHRU height generally followed the increase in WHRU heat transfer rate with increasing gas turbine input power, Fig. 24. This trend is modified only by a slightly increasing outside heat transfer coefficient with increasing gas turbine input power (see calculations for gas-side heat transfer coefficient in the model description).

As expected, the COGAS system specific fuel consumption improved (Fig. 25) with increasing gas turbine input power. This improvement represents the trend of improvement in the gas turbine itself with increasing power, since the

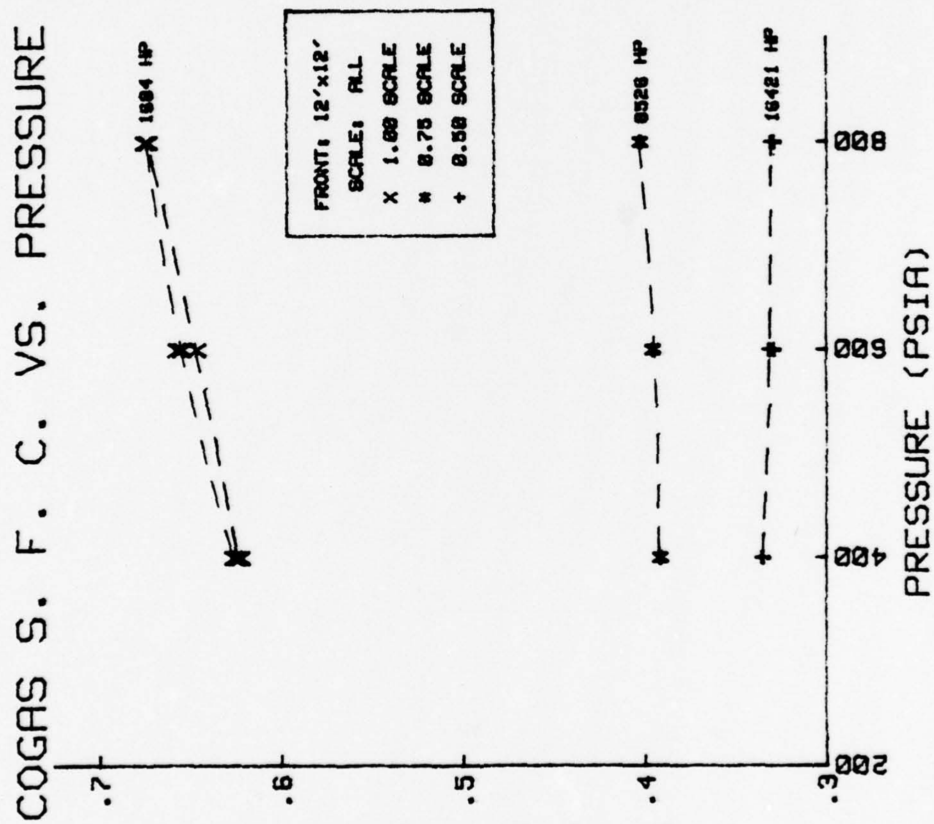

COGAS S. F. C. VS. PRESSURE
S. F. C. (LBM/HP-HR)
.3
.4
.5
.6
.7
200
400
600
800
PRESSURE (PSIA)
FRONT: 12'x12'
SCALE: ALL
x 1.00 SCALE
* 0.75 SCALE
+ 0.50 SCALE
16421 HP

FIGURE 22

COGAS SPECIFIC FUEL CONSUMPTION

GTHP	Pressure	Front: 12' X 12' Scale=1.0	Scale=0.75	Scale=0.50	Front: 12' X 15' Scale=1.0	Scale=0.75	Scale=0.50
	400	.335	.335	.336	.334	.335	.334
16421	600	.332	.331	.329	.331	.329	.329
	800	.330	.331	.329	.330	.329	.329
	400	.392	.392	.391	.391	.391	.392
8526	600	.395	.396	.396	.395	.395	.396
	800	.402	.403	.403	.401	.402	.400
	400	.624	.626	.622	.621	.621	.632
1684	600	.646	.654	.657	.648	.646	.650
	800	.675	.673	.675	.677	.675	.677

TABLE XIII

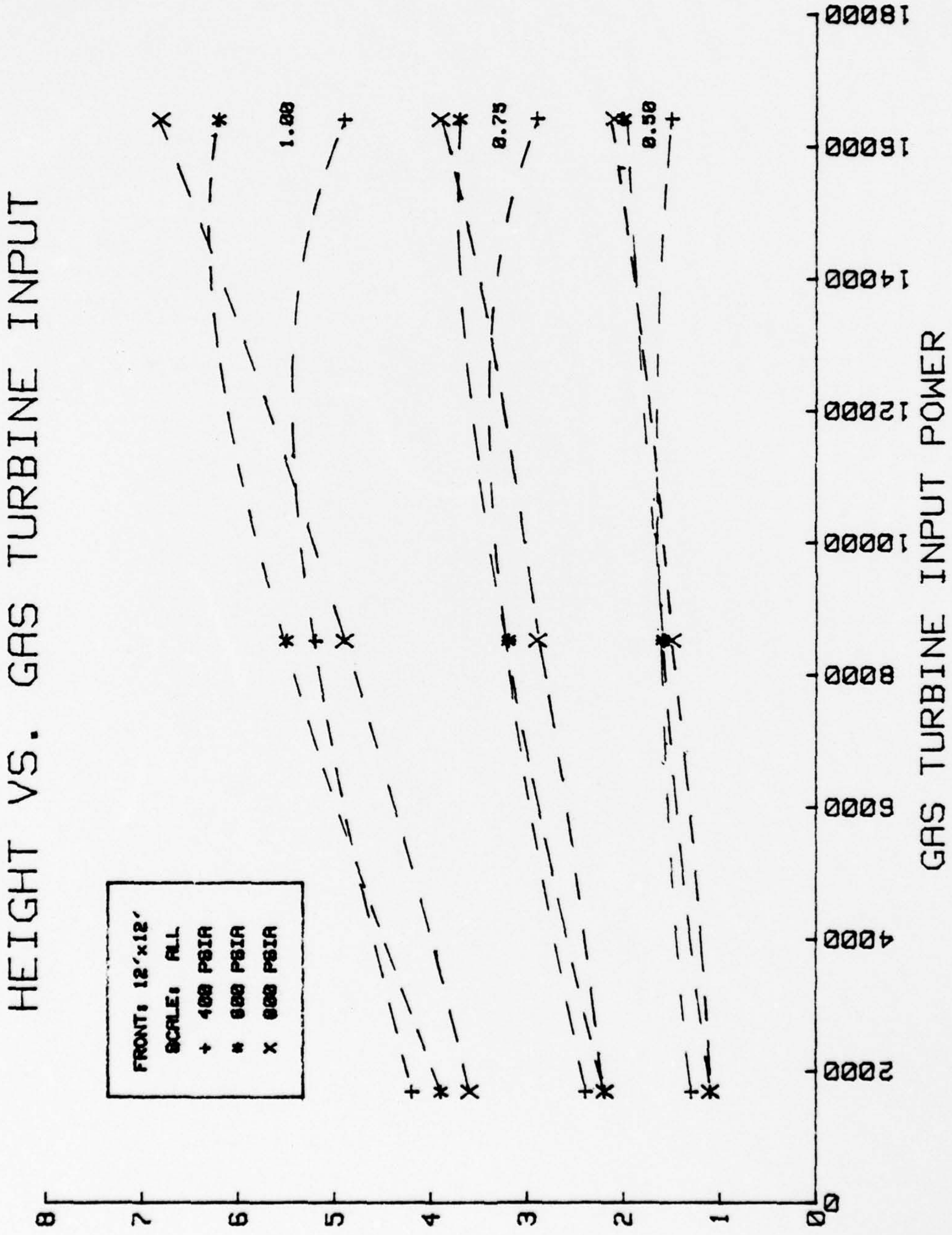
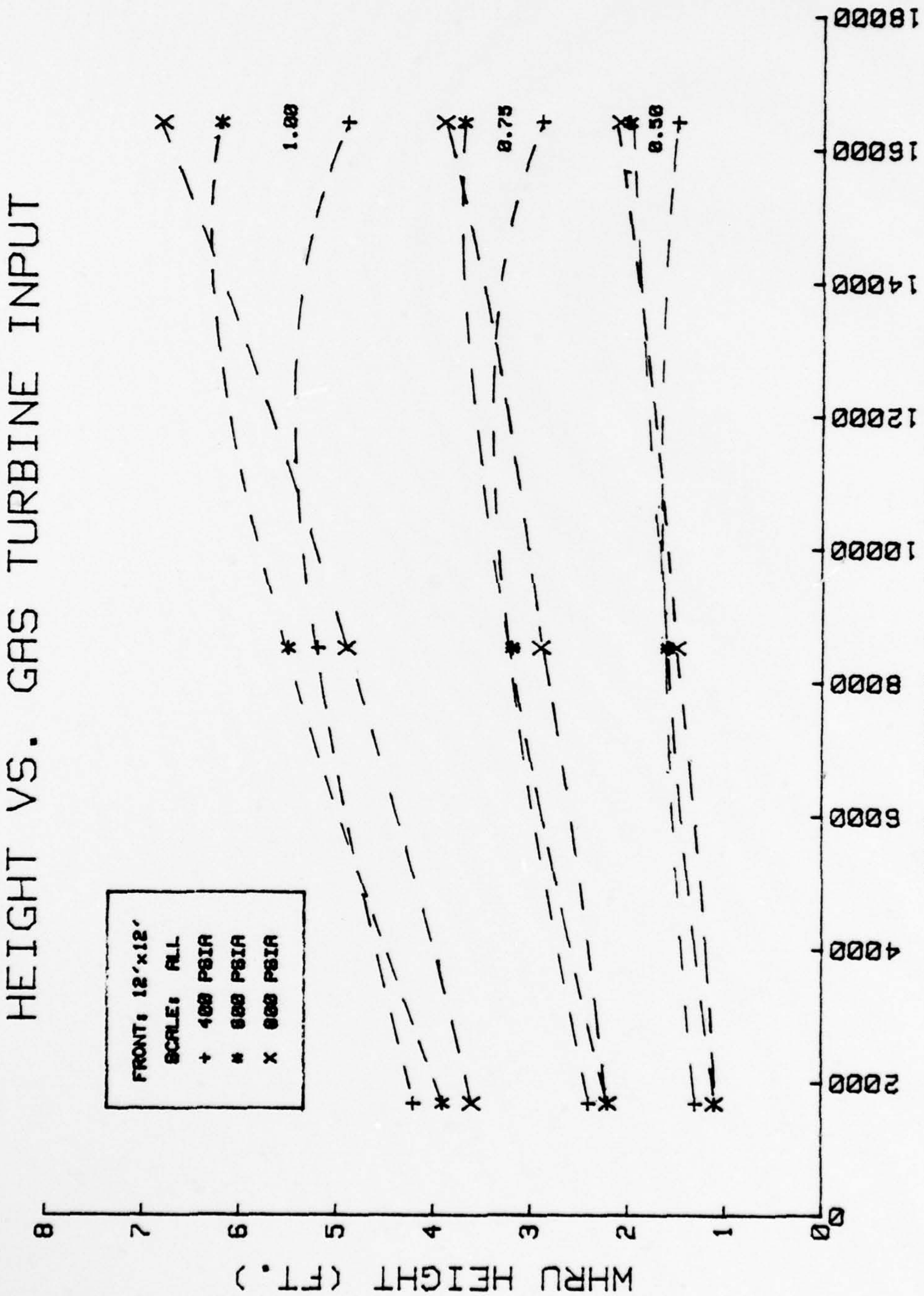

HEIGHT VS. GAS TURBINE INPUT
FRONT: 12'x12'
SCALE: ALL
+ 400 PSIA
* 600 PSIA
X 800 PSIA
1.00
0.75
0.50
WHRU HEIGHT (FT.)
GAS TURBINE INPUT POWER
0
1
2
3
4
5
6
7
8
2000
4000
6000
8000
10000
12000
14000
16000
18000

FIGURE 23



HEIGHT VS. GAS TURBINE INPUT
FRONT: 12'x12'
SCALE: ALL
+ 400 PSIA
* 600 PSIA
X 800 PSIA
1.00
0.75
0.50
WHRU HEIGHT (FT.)
GAS TURBINE INPUT POWER
0
1
2
3
4
5
6
7
8
2000
4000
6000
8000
10000
12000
14000
16000
18000

FIGURE 23

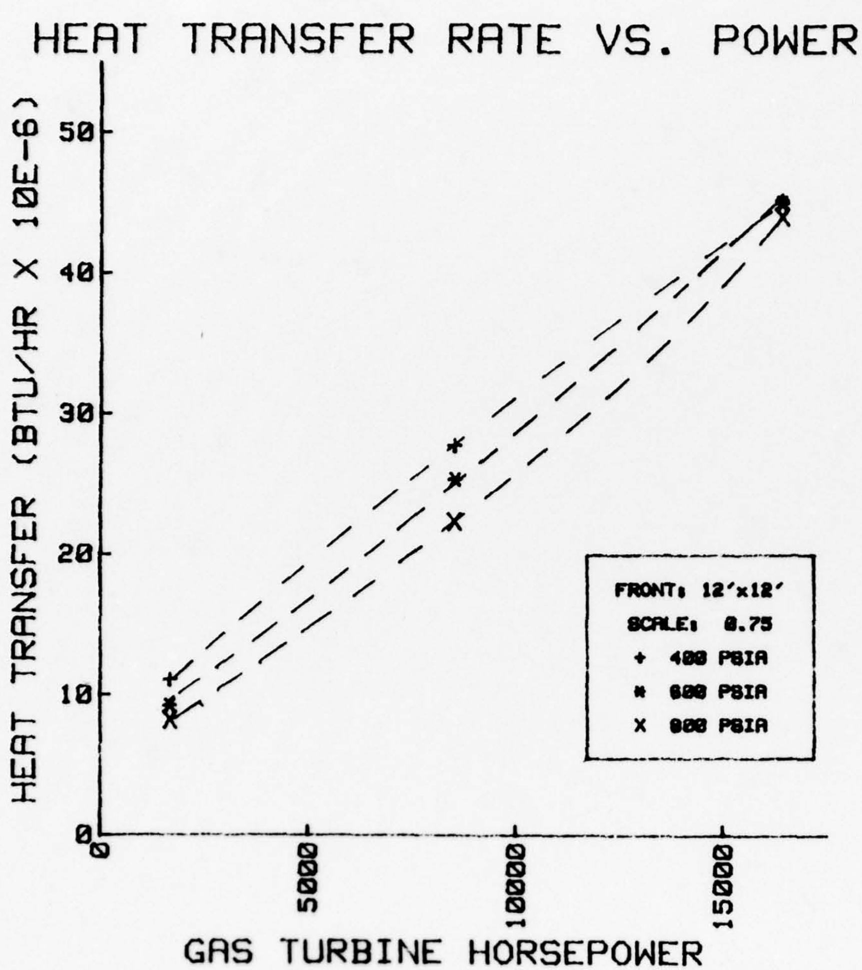

HEAT TRANSFER RATE VS. POWER
HEAT TRANSFER (BTU/HR X 10E-6)
0
10
20
30
40
50
0
5000
10000
15000
GAS TURBINE HORSEPOWER
FRONT: 12'x12'
SCALE: 0.75
+ 400 PSIA
* 600 PSIA
X 900 PSIA

FIGURE 24

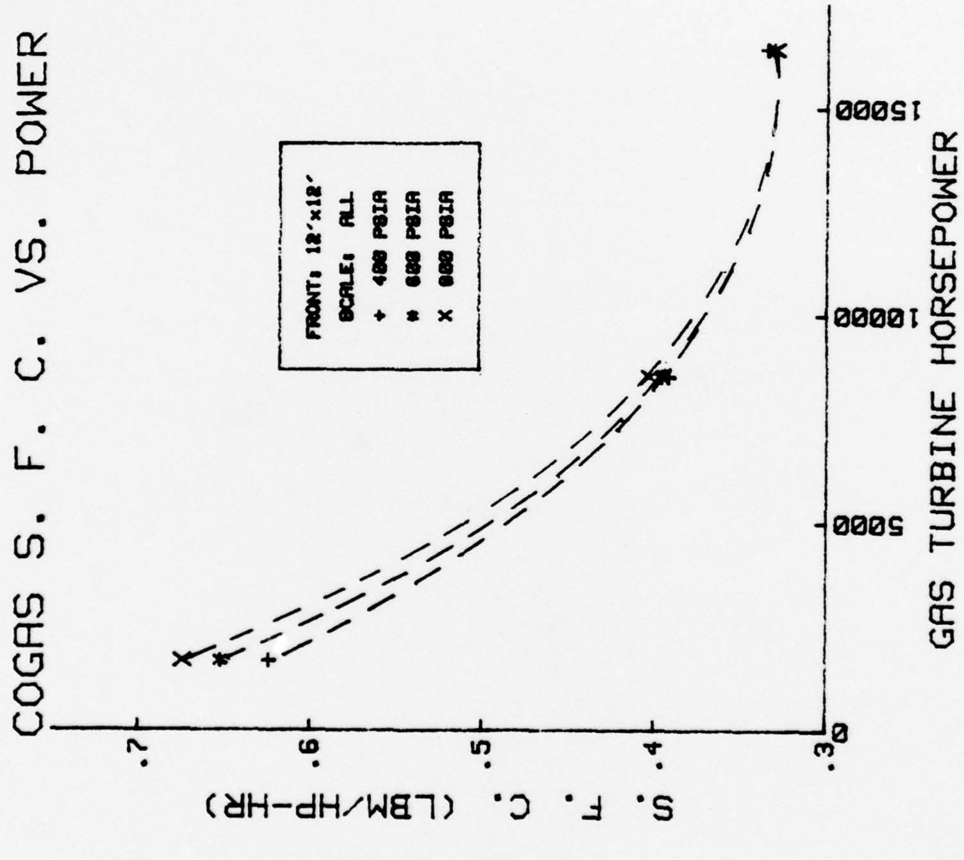

COGAS S. F. C. VS. POWER
S. F. C. (LBM/HP-HR)
.7
.6
.5
.4
.3
0
5000
10000
15000
GAS TURBINE HORSEPOWER
FRONT: 12'x12'
SCALE: ALL
+ 400 PSIA
* 600 PSIA
X 800 PSIA

FIGURE 25

contribution of the steam system decreases with increasing power.

Effect of Frontal Dimensions.

The only significant trends for changing frontal dimensions were in WHRU height and volume (see Tables III and XIV). The expected result of decreased height with increased frontal area was observed. The gas-side pressure drop follows this decrease in height. The WHRU volume showed a significant increase for increased frontal area for all designs produced. This result is consistent with the model formulation. That is, as the frontal area is increased and the tube length is held constant the area for fluid flow is increased with a consequent decrease in Reynolds number and inside heat transfer coefficient. The same result is seen in the outside heat transfer coefficient. As the frontal area is increased, the minimum flow area for the gas is increased, causing a drop in the gas side Reynolds number and heat transfer coefficient.

D. OFF-DESIGN RESULTS

The off-design results were produced using the same computer simulation program used to produce the design set. The method used for off-design runs was described in Section F of the model description. As the computer program is presently designed, the designer must manually adjust the inputs to produce an off-design run. The procedure is reviewed briefly below.

WHRU VOLUME [ft^3]

		Front: 12' X 12'			Front: 12' X 15'		
GTHP	Pressure	Scale=1.0	Scale=0.75	Scale=0.50	Scale=1.0	Scale=0.75	Scale=0.50
	400	705.6	417.6	216.0	828.0	486.0	270.0
16421	600	892.8	532.8	288.0	990.0	612.0	324.0
	800	979.2	561.6	302.4	1062.0	666.0	360.0
	400	748.8	460.8	230.4	882.0	522.0	270.0
8526	600	792.0	460.8	230.4	882.0	522.0	270.0
	800	705.6	417.6	216.0	828.0	486.0	270.0
	400	604.8	345.6	187.2	702.0	432.0	198.0
1684	600	561.6	316.8	158.4	648.0	396.0	198.0
	800	518.4	316.8	158.4	594.0	360.0	180.0

TABLE XIV

First, the designer selects a WHRU design to be investigated at off-design conditions. Once this design has been selected, the pressure, frontal dimensions, height and scale of the WHRU are fixed. The designer then enters the gas flow rate and gas inlet temperature corresponding to the off-design point to be investigated. A design is produced with these gas conditions and the physical characteristics of the WHRU design under consideration. The designer then checks the number of passes (height) for the resulting design. If the number of passes does not match that of the selected design, the WHRU gas outlet temperature and/or superheater steam outlet temperature are adjusted to increase or decrease the number of passes until a match is achieved. Once the physical characteristics of the off-design point WHRU match those of the design-point WHRU, the gas inlet temperature is matched with the initial conditions, and the performance of the selected WHRU design is established for the off-design point under consideration.

In order to test the feasibility of the procedure described above and to demonstrate the off-design performance of a wide variety of WHRU designs, ten WHRU designs were selected for off-design runs. These designs are listed in Table XVI. None of the full-scale designs was considered because the heights of the designs produced at that scale were, for the most part, either too large or borderline according to the space limitation described in Figure 9.

The results of these off-design runs are given in Table XVII. The summary output pages for each of these off-design runs along with the design-point runs are provided in Appendix D. In terms of specific fuel consumption, the performance difference between the design sets considered was not large. The performance range for fuel consumption is even less significant. Table XV demonstrates the performance range for the designs considered.

WHRU Off-Design Performance Ranges

Power	s.f.c.	fuel consumption (lbm/hr)	approx. fuel consumption difference (gal/hr)
high	.329 - .340	6992.8 - 7019.3	3.9
medium	.391 - .403	4429.2 - 4439.7	1.5
low	.615 - .658	1764.6 - 1767.5	0.4

Table XV

Since the fuel consumption comparison showed very little difference between the ten designs considered and since all designs considered satisfied the dimensional constraints of figures 7, 8, and 9, only two designs were selected for additional off-design runs.

For these additional off-design runs, a pressure of 600 psia was selected. This pressure did not produce the smallest designs but it is a steam pressure with which the Navy has some experience in terms of materials requirements, maintenance, and operation. A scale of 0.75 was selected

WHRU DESIGNS CONSIDERED

Design Run #	Pressure	Scale	Front	Design Power	Height
5	800	.75	12x12	med	2.9
14	600	.75	12x12	med	3.2
16	600	.50	12x12	high	2.0
22	400	.75	12x12	high	2.9
24	400	.75	12x12	low	2.4
35	800	.50	12x15	med	1.5
40	600	.75	12x15	high	3.4
41	600	.75	12x15	med	2.9
53	400	.50	12x15	med	1.5

TABLE XVI

WHRU OFF-DESIGN RESULTS

Run #	GT Power	Front/Scale	Height	HP	COGAS s.f.c.	GT s.f.c.	Steam Pressure	Fuel Consumption
4(0)	16421	12x12.1	2.9	20769	.337	.398	800	6999.1
5	8526	.75		10996	.403	.482		4431.4
6(0)	1684			2683	.658	.880		1765.4
16	16421	12x12	2.0	21286	.329	.387	600	7003.1
17(0)	8526	.50		11331	.391	.478		4430.1
18(0)	1684			2838	.622	.858		1765.2
22	16421	12x12.1	2.9	20874	.335	.396	400	6992.8
23(0)	8526	.75		11243	.394	.479		4429.7
24(0)	1684			2848	.620	.857		1765.8
22(0)	16421	12x12.1	2.4	20615	.340	.401	400	7009.1
23(0)	8526	.75		11073	.400	.481		4429.2
24	1684			2822	.626	.860		1766.6
34(0)	16421	12x15	1.5	20971	.334	.394	800	7004.3
35	8526	.50		11098	.400	.481		4439.2
36(0)	1684			2705	.653	.877		1766.4
40	16421	12x15.2	3.4	21269	.329	.387	600	6997.5
41(0)	8526	.75		11297	.393	.478		4439.7
42(0)	1684			2825	.625	.860		1765.6
40(0)	16421	12x15.2	2.9	21090	.332	.392	600	7001.9
41	8526	.75		11218	.395	.479		4431.1
42(0)	1684			2801	.630	.863		1764.6
52(0)	16421	12x15	1.5	21016	.334	.393	400	7019.3
53	8526	.50		11307	.392	.478		4432.3
54(0)	1684			2874	.615	.853		1767.5
13(0)	16421	12x12.1	3.2	20956	.334	.395	600	6999.3
14	8526	.75		11201	.396	.479		4435.6
15(0)	1684			2796	.632	.864		1767.1

TABLE XVII

which yields a tube outside diameter of 1.5 inches and a fin spacing of about 8 fins/inch. The rationale for this selection was that a scale of 0.50 with 1.0 inch OD tubes and a fin spacing of 12 fins/inch would probably be too susceptible to both inside and outside fouling. In order to achieve the closest possible comparison, the design-point for both designs selected was for the gas conditions corresponding to the medium (8526 BHP) gas turbine input horsepower. Both frontal areas were used for these detailed off-design runs. Table XVIII summarizes the characteristics of the two designs selected.

Final Design Characteristics

design run #	GT input design point	scale	front	pressure	height
14	8526	0.75	12 x 12	600	3.2
41	8526	0.75	12 x 15	600	2.9

Table XVIII

Table XIX summarizes the performance results for the COGAS system with the 12' x 12' front WHRU and Table XX gives the results for the system with the 12' x 15' front WHRU. In both cases, the performance characteristics of the gas turbine alone, at the COGAS system horsepower, are provided for comparison. The summary output pages for each of these runs are provided in Appendix E.

PERFORMANCE OF 12'x12' FRONT WHRU

GTHP (input)	COGAS HP	COGAS s.f.c.	GT s.f.t. (at COGAS HP)	COGAS fuel use	GT fuel use (at COGAS HP)	Steam Share
1684	2796	.632	.864	1765.9	2415.7	40.6
1895	3062	.624	.829	1910.4	2537.0	39.0
2105	3285	.622	.801	2024.8	2632.4	36.8
3158	4681	.551	.672	2576.9	3143.6	33.6
4316	6142	.491	.591	3018.1	3628.2	30.9
5474	7475	.455	.546	3404.2	4081.8	28.0
6947	9413	.413	.506	3890.8	4760.0	27.6
8526	11201	.396	.479	4432.6	5368.2	25.3
10421	13758	.370	.449	5085.2	6179.8	25.8
12105	15941	.354	.432	5636.4	6884.0	25.7
13790	17773	.347	.423	6161.2	7525.7	24.1
16421	20956	.334	.395	6997.8	8268.2	23.4
20000	25406	.322	.463	8180.7	11762.9	23.2

TABLE XIX

PERFORMANCE OF 12'x15' FRONT WHRU

GTHP (input)	COGAS HP	COGAS s.f.c.	GT s.t.c. (at COGAS HP)	COGAS fuel use	GT fuel use (at COGAS HP)	Steam Share
1684	2802	.630	.863	1776.2	2418.9	40.7
1895	3061	.624	.829	1910.7	2536.6	38.9
2105	3290	.621	.801	2043.1	2634.3	36.9
3158	4681	.551	.672	2571.1	3158.8	33.5
4316	6175	.489	.589	3018.3	3639.4	31.2
5474	7530	.452	.545	3404.5	4100.7	28.4
6947	9440	.412	.505	3892.0	4769.3	27.6
8526	11218	.395	.479	4434.8	5373.6	25.2
10421	13808	.369	.449	5088.5	6195.5	25.8
12105	16038	.352	.431	5640.5	6916.9	25.9
13790	17889	.345	.423	6165.9	7566.7	24.3
16421	21085	.332	.392	7006.4	8259.9	23.6
20000	25582	.320	.463	8186.2	11844.5	23.3

TABLE XX

The specific fuel consumption curves vs. brake horsepower for the 12' x 12' front and the 12' x 15' front are plotted in figures 26 and 27 respectively. The difference in s.f.c. performance between the two WHRU designs considered was not significant. Geometric considerations were therefore used in selecting the better of these two designs. A geometric comparison of the two WHRU designs is given in Table XXI.

Geometric Comparison of the Final Two Designs

Front	Frontal Area	Height	Volume	Total Outside Area
12' x 15'	181.9	2.9	528.96	49586.4
12' x 12'	144.8	3.2	464.64	42776.5

Table XXI

It was concluded that, since both designs met the height constraint of figure 9, the 12' x 12' front was the better choice because of the significantly lower volume and total outside area requirements.

After the selection of the 12' x 12' front WHRU as the final design, estimates were made of the possible COGAS fuel savings for a DD-963-type destroyer over 1000 hours of operation. The NAVSEC Standard Destroyer Profile (Fig. 28) was used to determine the number of hours a destroyer-type ship spends at each speed during 1000 hours operation.

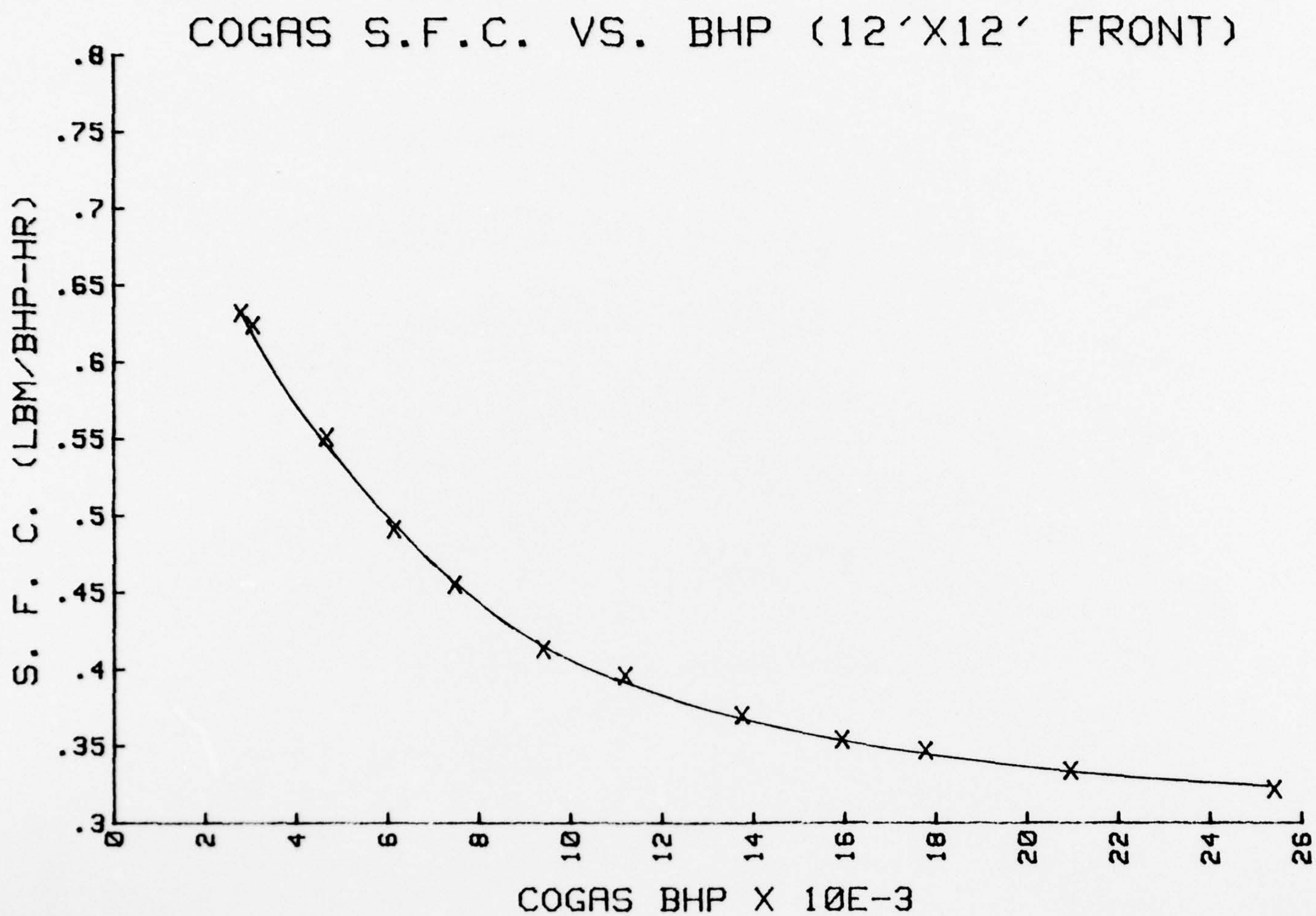

COGAS S.F.C. VS. BHP (12'X12' FRONT)
S. F. C. (LBM/BHP-HR)
.8
.75
.7
.65
.6
.55
.5
.45
.4
.35
.3
0
2
4
6
8
10
12
14
16
18
20
22
24
26
COGAS BHP X 10E-3

FIGURE 26

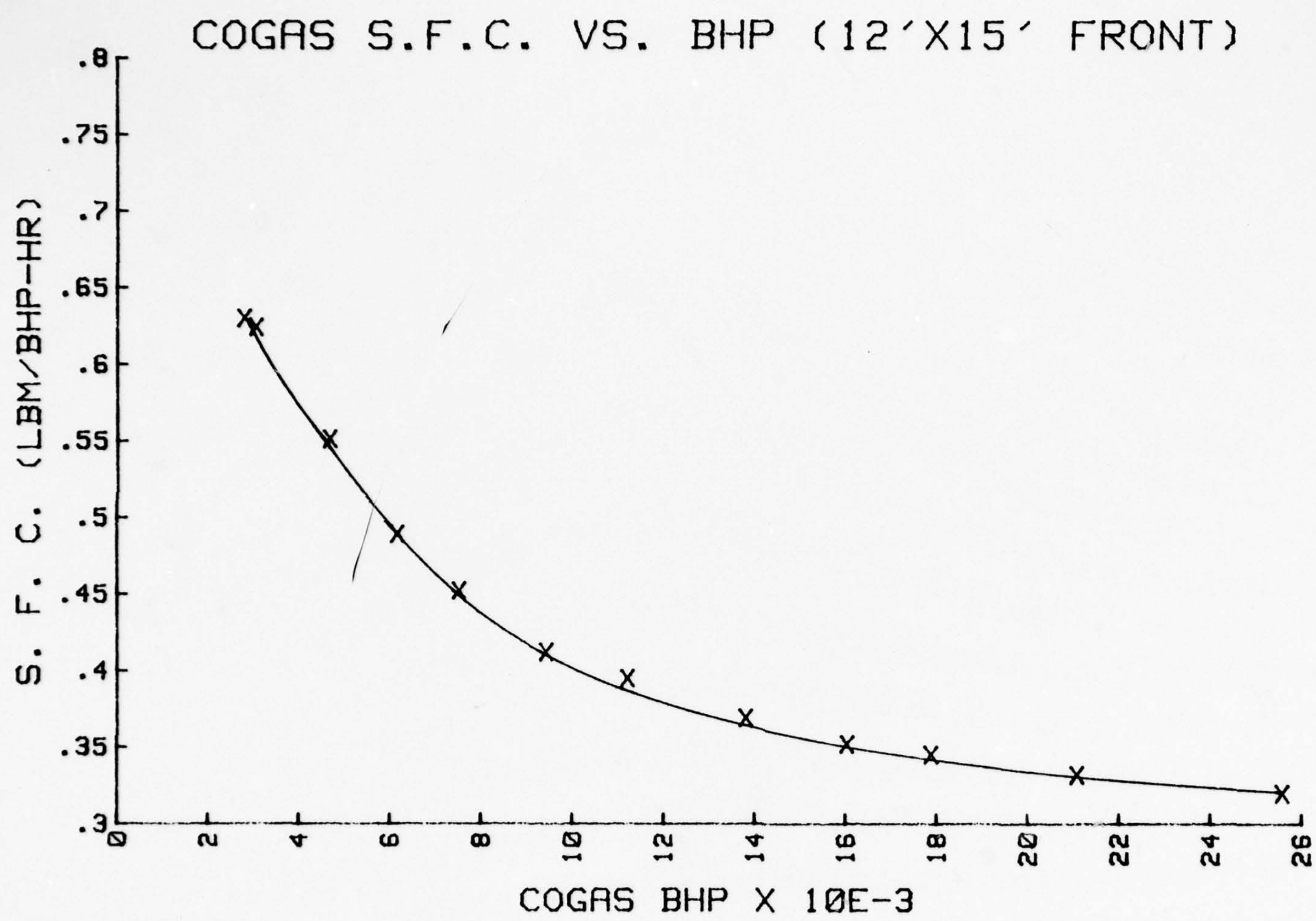
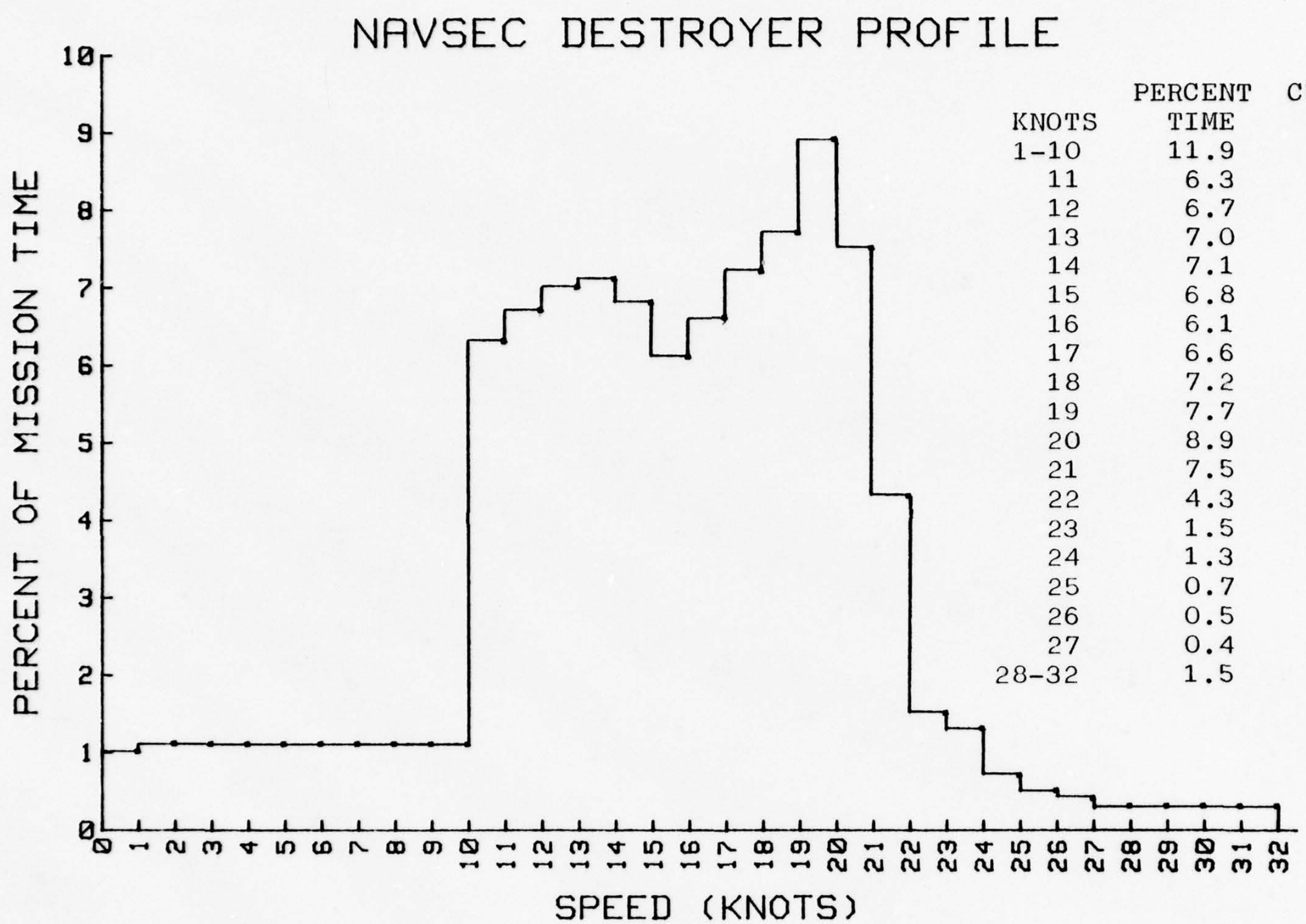

COGAS S.F.C. VS. BHP (12'X15' FRONT)
S. F. C. (LBM/BHP-HR)
.8
.75
.7
.65
.6
.55
.5
.45
.4
.35
.3
0
2
4
6
8
10
12
14
16
18
20
22
24
26
COGAS BHP X 10E-3

FIGURE 27



KNOTS	PERCENT TIME	CUMULATIVE PERCENT
1-10	11.9	11.9
11	6.3	18.2
12	6.7	24.9
13	7.0	31.9
14	7.1	39.0
15	6.8	45.8
16	6.1	51.9
17	6.6	53.5
18	7.2	65.7
19	7.7	73.4
20	8.9	82.3
21	7.5	89.8
22	4.3	94.1
23	1.5	95.6
24	1.3	96.9
25	0.7	97.6
26	0.5	98.1
27	0.4	98.5
28-32	1.5	100.0

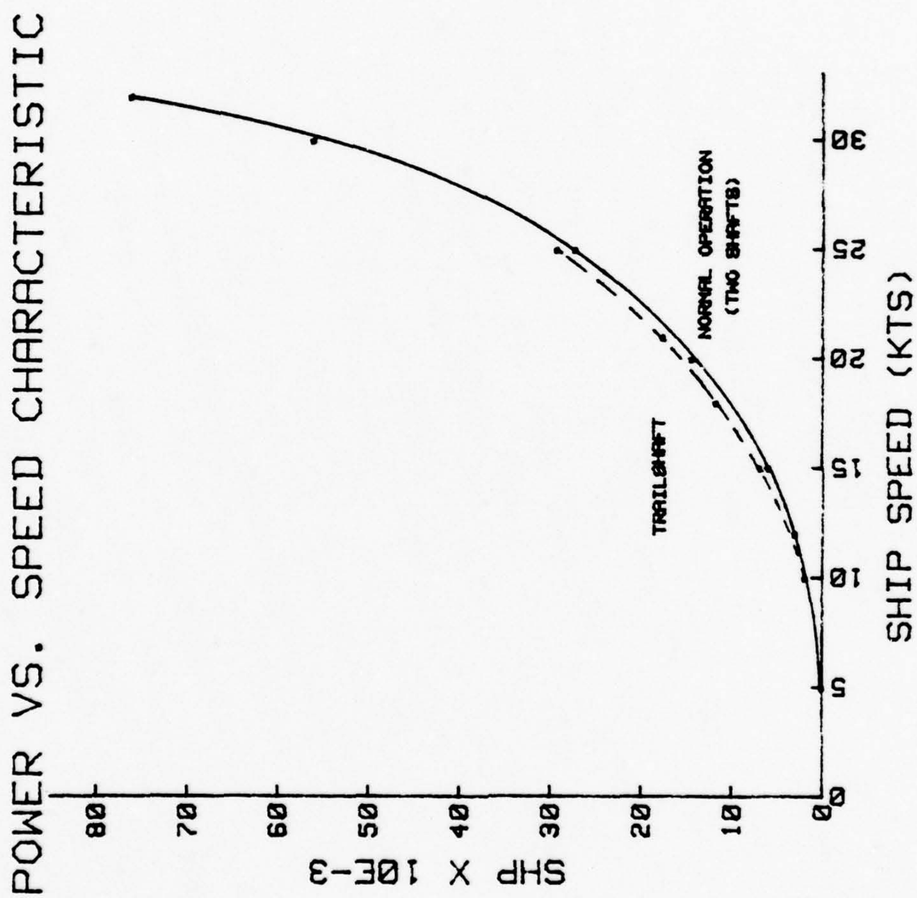
FIGURE 28

Figure 29 was used to obtain the shaft horsepower requirements for each speed. Finally, figure 30 was used to obtain the s.f.c. of the gas turbine operating alone.

Two estimates of fuel savings were made. The first estimate assumed that the COGAS system would be operated for speeds of 5 to 20 knots and would be secured outside that range. The second estimate employed the COGAS system for speeds of 5 to 23 knots. For the latter operating range, the criterion for the high COGAS speed was an imposed maximum gas turbine horsepower input of 20000 BHP. Both fuel savings estimates are based on the following assumptions and simplifications:

1. The COGAS mode of operation implies the use of one engine (COGAS mode) on one shaft with the other shaft dragging.
2. The gas turbine is assumed to operate at idle (1000 BHP) at speeds below 8 knots.
3. Maneuvering combinations, when two main engines would normally be on the line, are not considered.
4. In the speed range of 21 to 27 knots, in the pure gas turbine mode, one engine per shaft is used, with two shafts on the line.
5. From 28 to 32 knots four gas turbines are on the line.

Table XXII provides the estimates of s.f.c. and fuel consumption for COGAS between 5 and 20 knots and for pure gas turbine for all speeds. The total estimated fuel savings



POWER VS. SPEED CHARACTERISTIC
SHP X 10E-3
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
30
SHIP SPEED (KTS)
TRAILSHAFT
NORMAL OPERATION
(TWO SHAFTS)

FIGURE 29

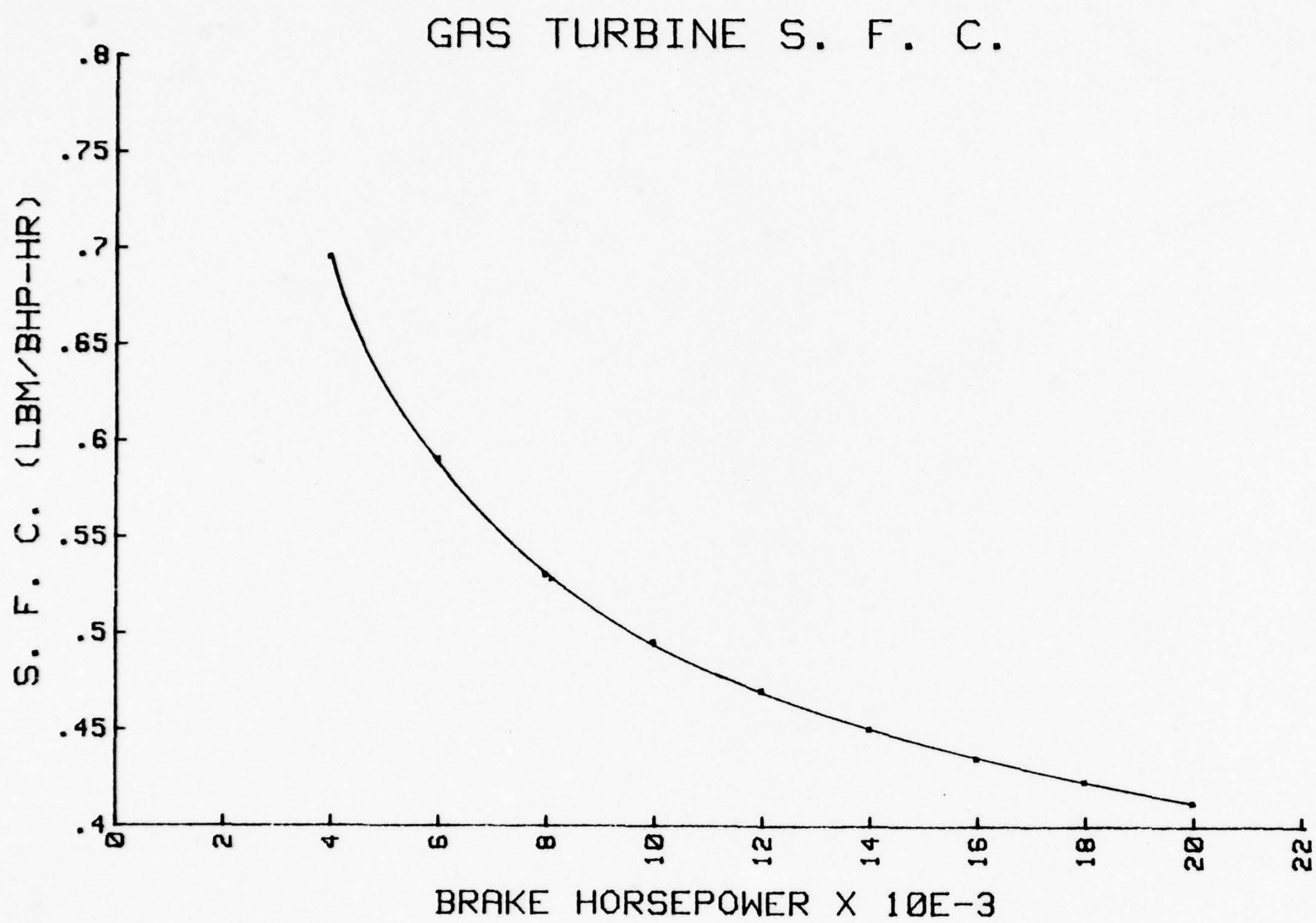

GAS TURBINE S. F. C.
S. F. C. (LBM/BHP-HR)
.8
.75
.7
.65
.6
.55
.5
.45
.4
0
2
4
6
8
10
12
14
16
18
20
22
BRAKE HORSEPOWER X 10E-3

FIGURE 30

COGAS PERFORMANCE: 5 to 20 KNOT RANGE

Speed	Hours	BHP	COGAS s.f.c.	GT s.f.c.	COGAS CONS	GT CONS
1	10					17510
2	12.1					21187
3	12.1					21187
4	12.1	GT IDLE at 1000	est. avg. .800	est. avg. 1.751		21187
5	12.1				9680	21187
6	12.1				9680	21187
7	12.1				9680	21187
8	12.1				9680	21187
9	12.1	1684	.750	1.100	15282	22414
10	12.1	1895	.705	1.070	16165	24534
11	63	2105	.680	1.000	90178	132615
12	67	3158	.618	.820	130760	173500
13	70	4316	.560	.700	169187	211484
14	71	5579	.512	.610	202808	241626
15	68	7368	.460	.550	230471	275563
16	61	8947	.426	.515	232497	281070
17	66	10421	.400	.489	275114	336327
18	72	12316	.380	.460	339666	407906
19	77	14210	.365	.440	399372	481435
20	89	16526	.350	.433	514785	636862

TABLE XXII

Page 1

Speed	Hours	BHP	COGAS s.f.c.	GT s.f.c.	COGAS CONS	GT CONS
21	75	17368		.519		676049
22	43	20000		.495		425700
23	15	22105		.482		159819
24	13	25263		.463		152058
25	7	28684		.448		89953
26	5	32631		.435		70972
27	4	37895		.418		63360
28	3	44210		.482		62928
29	3	51580		.460		71180
30	3	58947		.444		78517
31	3	69474		.427		88996
32	3	78947		.415		98289
					4774897	5429976

12.1% savings

over 1000 hrs operation

655088 lbm savings

or 96336 gal. dist. fuel

TABLE XXII

Page 2

over 1000 hours of operation was 12% which is roughly equivalent to 96000 gallons of distillate fuel.

The estimates of s.f.c. and fuel consumption for pure gas turbine and for COGAS for the 5 to 23 knot speed range are given in Table XXIII. The total estimated 1000-hour fuel savings for this COGAS operating range was 19% which translates to approximately 152000 gallons of distillate fuel.

E. CONCLUSIONS

The waste heat recovery unit model and the accompanying simple COGAS system output model provide the basic framework for additional studies of the application of the COGAS system to U. S. Navy gas turbine powered ships. The model, as presently formulated, provides a reasonable estimate of WHRU size required for the fin-tube configuration considered.

Estimates of the COGAS system performance in the 5 to 20 knot range and the 5 to 23 knot range are encouraging. Even considering the assumptions involved in making the fuel savings estimates, it is likely that a COGAS version of a DD-963-type ship would consume on the order of 300000 to 450000 gallons less fuel in one year of operation than the current DD-963 class ships.

The most probable COGAS system would be one which would be designed to operate in non-maneuvering situations for either speed range considered above. That is, a system which would be employed for maximum fuel savings in the cruise mode.

COGAS PERFORMANCE: 5 t0 23 KNOT RANGE

Speed (kts)	Hours	BHP	COGAS s.f.c. (lbm/ hp-hr)	GT s.f.c. (lbm/ hp-hr)	COGAS CONS (lbm)	GT CONS (lbm)
1	10					17510
2	12.1					21187
3	12.1					21187
4	12.1	GT IDLE at 1000	EST. AVG. .800	EST. AVG. 1.751		21187
5	12.1				9680	21187
6	12.1				9680	21187
7	12.1				9680	21187
8	12.1				9680	21187
9	12.1	1684	.750	1.100	15282	22414
10	12.1	1895	.705	1.070	16165	24534
11	63	2105	.680	1.000	90178	132615
12	67	3158	.618	.820	130760	173500
13	70	4316	.560	.700	169187	211484
14	71	5579	.512	.610	202808	241626
15	68	7368	.460	.550	230471	275563
16	61	8947	.426	.515	232497	281070
17	66	10421	.400	.489	275114	336327
18	72	12316	.380	.460	339666	407906
19	77	14210	.365	.440	399372	481435
20	89	16526	.350	.433	514785	636862

TABLE XXIII

Page 1

Speed	Hours	BHP	COGAS s.f.c.	GT s.f.c.	COGAS CONS	GT CONS
21	75	18421	.340	.519	469735	676049
22	43	20842	.335	.495	300229	425700
23	15	23368	.324	.482	113568	159819
24	13	252263		.463		152058
25	7	28684		.448		89953
26	5	32631		.435		70972
27	4	37895		.418		63360
28	3	44210		.482		63928
29	3	51580		.460		71180
30	3	58947		.444		78517
31	3	69474		.427		88996
32	3	78947		.415		98289
			Totals:		4396861	5429976

19.0% savings

fuel saved in 1000 hrs operation

1033115 lbm

or 151928 ga. dist. fuel

TABLE XXIII

Page 2

During maneuvering and high speed operations the gas turbines would be operated alone with the waste heat recovery unit dry. Because of the relatively low gas turbine exhaust temperatures involved, it is not expected that damage would occur in the WHRU when operated dry.

IV. RECOMMENDATIONS FOR FURTHER RESEARCH

A. WHRU DESIGN MODEL IMPROVEMENT AND EXPANSION

The type of control imposed on the WHRU design model of this thesis was essentially the adjustment of the steam flow rate to maintain a superheater steam outlet temperature of 650 F at the pressure specified. This steam flow rate control was further extended to accommodate the maintenance of a minimum pinch point ΔT of 25 F. Further investigation of WHRU design should include the effects of allowing the superheater outlet steam temperature and/or pressure to "float" with changing gas turbine exhaust conditions. The combination of controls on the superheater outlet pressure, temperature, and flow rate could lead to improved WHRU output while still maintaining an acceptable minimum pinch point temperature difference.

In order to increase the precision of the model and lead to increased knowledge of the gas temperature distribution in the WHRU, the present model could be modified for a "fine mesh" approach. That is, instead of solving one pass at a time, each pass could be divided into a number of segments. The solution could then proceed using either the finite difference or finite element method.

Other possible model improvements are as follows:

1. Include the calculation of fluid/steam-side pressure drop.

2. Additional fin-tube configurations should be considered for possible improvement of the heat transfer characteristics and the weight and space requirements of the WHRU.

3. Consideration of inside and outside heat transfer surface fouling should be given when investigating possible fin-tube configurations.

4. Working fluids other than water should be investigated for possible enhanced thermodynamic characteristics at a minimum cost in system maintainability.

B. COGAS MODEL IMPROVEMENTS

After the waste heat recovery unit, the steam turbine and condenser should have the highest priority for modeling. Both of these units were modeled as "black boxes" in this model. The modeling or performance mapping of "state of the art" steam turbines for application in the COGAS model would allow the designer to further refine the estimate of system performance for various WHRU outputs of steam temperature, pressure, and flow rate. The inclusion of a steam turbine model would also allow the designer to make size and weight estimates for that component. The same benefits would be derived from the inclusion of a condenser model in the COGAS system. As the condenser pressure is reduced, the system performance should improve. The improvement must, however, be weighed against the increased condenser size necessary at the reduced pressure for constant steam and cooling water

conditions. A condenser model would allow the designer to make these comparisons.

In the model of this thesis, pumping power for the condensate and feedwater was assumed to be negligible. In the case of the condensate pump, this is probably not a bad assumption since it is likely that electric pumps could be used, and the cost to the ship's electrical output would not be large. The feedwater pump, however, would probably be steam turbine driven at some cost to the COGAS system output. The required feed pump pumping power for various loads should be mapped and included in the model.

Finally, the likely engineroom machinery layout for the COGAS system should be described in enough detail that the lengths of piping runs, number of turns, and location of valves could be estimated. The inclusion of this feature in the model would allow the designer to address pressure drop and heat losses between components. This feature would also contribute to the COGAS system weight and space prediction.

C. SYSTEM OPTIMIZATION

Since the COGAS system is operated with a relatively small heat source, optimization should be attempted in the design of the system. The technique of non-linear programming could be applied to a COGAS system optimization where an important system output parameter, say specific fuel consumption, is expressed as a function of the system design

variables such as component weight, component dimensions, and gas turbine backpressure. This function is called the objective function, and it is maximized or minimized subject to constraints which are also expressed as functions of the design variables. These constraint functions may be either linear or non-linear and express some parameter limit not to be exceeded, such as WHRU or condenser total volume.

For a system of the complexity of the COGAS system a "local" optimization appro would probably have to be adopted. That is, each of the major sub-models (WHRU, steam turbine, and condenser) could be optimized using local constraints. Then the entire system could be optimized using linking variables, such as enthalpy, flow rates, and temperatures between components. The process would be repeated as many times as necessary to achieve the final system optimization. One available computer-based system using the technique of non-linear programming is the COPES/CONMIN program [Ref. 14].

APPENDIX A

MAIN PROGRAM LISTING

```
C     THIS PROGRAM IS THE MAIN, OR CALLING, PROGRAM IN A SET OF
C     PROGRAMS USED TO DESIGN A ONCE-THROUGH WASTE HEAT EXCHANGER TC
C     PROVIDE STEAM FOR A COMBINED GAS AND STEAM (COGAS) PROPULSION
C     SYSTEM.  THE FOLLOWING SUBPROGRAMS ARE USED IN CONJUNCTION WITH
C     THE MAIN PROGRAM.
C
C     SUBROUTINE HBAL:  CALCULATES INITIAL HEAT BALANCE AND ESTABLISHES
C     STEAM FLOW RATE GIVEN INPUTS OF GAS TEMP. IN AND OUT, GAS FLOW,
C     WATER TEMP. IN, STEAM TEMP. OUT, STEAM PRESSURE.
C
C     SUBROUTINE GEO1:  CALCULATES ALL NECESSARY AREAS AND DIMENSIONS
C     FOR A FIXED FIN-TUBE CONFIGURATION GIVEN INPUTS OF SCALE, NUMBER
C     OF TUBES PER ROW, AND TUBE LENGTH.
C
C     SUBROUTINE SAT1:  CALCULATES GAS TEMP. IN, WATER TEMP. OUT, ANC
C     NUMBER OF PASSES NECESSARY FOR THE HEATING SECTION OF THE HEAT
C     EXCHANGER.
C
C     SUBROUTINE BOIL1:  CALCULATES GAS TEMP. IN, STEAM QUALITY OUT,
C     AND NUMBER OF PASSES NECESSARY FOR THE BOILING SECTION OF THE
C     HEAT EXCHANGER.
C
C     SUBROUTINE SUP1:  CALCULATES GAS TEMP. IN, STEAM TEMP. OUT, AND
C     NUMBER OF PASSES NECESSARY FOR THE SUPERHEATING SECTION OF THE
C     HEAT EXCHANGER.
C
C     SUBROUTINE OPTM:  ADJUSTS HEAT EXCHANGER GAS OUTLET TEMP. IN
C     ORDER TO MATCH GAS INLET TEMP. TO THAT ORIGINALLY SPECIFIED.
C
C     SUBROUTINES TEMP/TEMP1:  CALCULATES TEMPREATURE GIVEN ENTHALPY
C     AND PRESSURE.
C
C     SUBROUTINE FINE:  CALCULATES FIN EFFICIENCY GIVEN GEOMETRIC INPUTS
C     FROM GEO1 AND GIVEN CURRENT HEAT TRANSFER CCEFFICIENT.
C
C     SUBROUTINE OUT:  PRODUCES ONE-PAGE, OFF-LINE SUMMARY OUTPUT
C     FOR EACH DESIGN.
C
C     THE PROGRAM IS INTERACTIVE AND DESIGNED TO BE RUN ON THE TIME
C     SHARING SYSTEM OF THE IBM 360-67 COMPUTER.  ALL DESIGNER INPUTS
C     ARE PROMPTED AT THE TERMINAL.
C
C
C
      IMPLICIT REAL*4(L)
      LOGICAL OPA,OP,RED,OD,NDR,DES,OPT,SUM
      SUM=.FALSE.
      OPT=.FALSE.
```

```
      OD=.FALSE.                                                        WHR00490
      GC=4.1538E8                                                       WHR00500
      PATM=2116.368                                                     WHR00510
      TCM=26.                                                           WHR00520
      PI=3.1416                                                         WHR00530
      FFI=.3                                                            WHR00540
      FFO=.98                                                           WHR00550
      FFT=.025                                                          WHR00560
      RR=53.34                                                          WHR00570
      RCONV=459.69                                                      WHR00580
      PP=25.                                                            WHR00590
      CS=0.                                                             WHR00600
      TINC=1.5                                                          WHR00610
      OPT=.FALSE.                                                       WHR00620
      WRITE(6,90)                                                       WHR00630
90    FORMAT('0','SUPRESS ALL OUTPUT?')                                 WHR00640
      READ(5,92) CPA                                                    WHR00650
92    FORMAT(L4)                                                        WHR00660
      WRITE(6,94)                                                       WHR00670
94    FORMAT('0','GEOMETRIC SCALING ?')                                 WHR00680
      READ(5,95) SCALE                                                  WHR00690
95    FORMAT(F4.2)                                                      WHR00700
      WRITE(6,96)                                                       WHR00710
96    FORMAT('0','IS THIS A DESIGN RUN?')                               WHR00720
      READ(5,97) DES                                                    WHR00730
97    FORMAT(L4)                                                        WHR00740
      IF(DES) GO TO 10                                                  WHR00750
      OD=.TRUE.                                                         WHR00760
C                                                                       WHR00770
C     CONSTANTS                                                         WHR00780
C                                                                       WHR00790
199   GC=4.1538E8                                                       WHR00800
      PATM=2116.368                                                     WHR00810
      TCM=26.                                                           WHR00820
      PI=3.1416                                                         WHR00830
      FFI=.3                                                            WHR00840
      FFO=.98                                                           WHR00850
      FFT=.025                                                          WHR00860
      RR=53.34                                                          WHR00870
      RCONV=459.69                                                      WHR00880
      PP=25.                                                            WHR00890
10    WRITE(6,198)                                                      WHR00900
198   FORMAT('0','ENTER GT HORSEPOWER.')                                WHR00910
      READ(5,197) HPGT                                                  WHR00920
197   FORMAT(F8.1)                                                      WHR00930
      WRITE(6,196)                                                      WHR00940
196   FORMAT('0','ENTER SHIP SPEED.')                                   WHR00950
      READ(5,195) SSPD                                                  WHR00960
```

```
195   FORMAT(F4.1)                                                    WHR00970
C                                                                     WHR00980
C     MAKE INITIAL CALCULATIONS                                       WHR00990
C                                                                     WHR01000
      CALL HBAL(TG1,TG2,TG3,TG4,TF1,TF2,TF3,TF4,GG,GF,OPA,PF1,OPT,    WHR01010
     XOD)                                                             WHR01020
      TG1P=TG1                                                        WHR01030
      TG2P=TG2                                                        WHR01040
      TG3P=TG3                                                        WHR01050
      TG4P=TG4                                                        WHR01060
      TF1P=TF1                                                        WHR01070
      TF2P=TF2                                                        WHR01080
      TF3P=TF3                                                        WHR01090
      TF4P=TF4                                                        WHR01100
C                                                                     WHR01110
C     CALCULATIONS FOR SATUFATOR                                      WHR01120
C                                                                     WHR01130
20    TGB1=(TG3+TG4)/2.                                               WHR01140
      DPGT=0.                                                         WHR01150
      TGF1=TGB1                                                       WHR01160
      CALL SATI(GG,GF,TGF1,TGB1,EFFSA,TF2,TFB1,TCM,FG,PF1,TG3,TG4,TF1, WHR01170
     XR,TWO,GGM,LT,UF,DI,HOSAT,OPA,SCALE,IPSA,OPT,ANTR,L,SUM,REFS)    WHR01180
C                                                                     WHR01190
C     GAS SIDE PRESSURE DROP                                          WHR01200
C                                                                     WHR01210
      VGW=VISG(TWO)                                                   WHR01220
      VGB=VISG(TGB1)                                                  WHR01230
      TGFR=TGF1+RCONV                                                 WHR01240
      VCLG=RR*TGFR/PATM                                               WHR0125C
      DPG=(2.*FG*GGM**2*R*VOLG/GC)*(VGW/VGB)**.14                     WHR01260
      DPGT=DPGT+DPG                                                   WHR01270
      IF(OPA) GO TO 24                                                WHR01280
      WRITE(6,150) DPG                                                WHR01290
150   FORMAT('0','DPG=',F5.1)                                         WHR01300
      WRITE(6,170) TF2                                                WHR01310
170   FORMAT('0','TF2=',F6.2)                                         WHR01320
C                                                                     WHR01330
C     CALCULATIONS FOR BOILER                                         WHR01340
C                                                                     WHR01350
24    CALL BOIL1(GG,GF,TG2,TG3,TF2,TF3,TFB,TGF,FG,PF1,HF3,X3,TGB,     WHR0136C
     XTWO,GGM,R,OPA,SCALE,IPB,OPT,TGIB1,AIH,SUM)                      WHR01370
C                                                                     WHR01380
C     GAS SIDE PRESSURE DROP                                          WHR01390
C                                                                     WHR01400
      VGW=VISG(TWO)                                                   WHR01410
      VGB=VISG(TGB)                                                   WHR01420
      TGFR=TGF+RCONV                                                  WHR01430
      VCLG=RR*TGFR/PATM                                               WHR01440
```

```
      DPG=(2.*FG*GGM**2*R*VOLG/GC)*(VGW/VGB)**.14                       WHR01450
      DFGT=DPGT+DPG                                                     WHR01460
      IF(OPA) GO TO 26                                                  WHR01470
      WRITE(6,190) DPG                                                  WHR01480
190   FCRMAT('0','DPG=',F5.1)                                           WHR01490
C                                                                       WHR01500
C     CALCULATIONS FOR SUPERHEATER                                      WHR01510
C                                                                       WHR01520
26    CALL SUP1(GG,GF,TG1,TG2,TF3,TF4,FG,PF1,X3,HFCUT,TGINS,            WHR01530
     XTGB,TWD,TGF,GGM,OPA,SCALE,IFR,IPSH,TG1,TF4,CPT,IPT,IPB,IPSA,      WHR01540
     XAIB,SUM,R,REFSH)                                                  WHR01550
C                                                                       WHR01560
C     GAS SIDE PRESSURE DROP                                            WHR01570
C                                                                       WHR01580
      VGW=VISG(TWC)                                                     WHR0159C
      VGB=VISG(TGB)                                                     WHR01600
      TGFR=TGF+RCONV                                                    WHR01610
      VCLG=RR*TGFR/PATM                                                 WHR01620
      DPG=(2.*FG*GGM**2*R*VOLG/GC)*(VGW/VGB)**.14                       WHR01630
      DPGT=DPGT+DPG                                                     WHR01640
      DPGT=27.7*(DPGT/144.)                                             WHR01650
      WRITE(6,190) DPG                                                  WHR01660
      IFT=IPSA+IPB+IPSH                                                 WHR01670
      IF(OPT) GO TO 29                                                  WHR01680
C                                                                       WHR01690
C     MATCH GAS TEMP. IN                                                WHR0170C
C                                                                       WHR01710
      WRITE(6,192)                                                      WHR01720
192   FCRMAT('0','MATCH TG4?')                                          WHR0173C
      READ(5,92) OPT                                                    WHR01740
      IF(.NOT.OPT) GO TO 28                                             WHR01750
29    CALL OPTM(TG1P,TG1,TG4P,CS,OK,TINC)                               WHR01760
      WRITE(6,1000) TG1P,TG4P                                           WHR01770
1000  FORMAT('0',2F7.1)                                                 WHR0178C
      IF(OK.EQ.0.) GO TO 28                                             WHR01790
C                                                                       WHR01800
C     REPERFORM INITIAL CALCULATIONS WITH NEW GAS TEMP. OUT             WHR01810
C                                                                       WHR01820
      CALL HBAL(TG1P,TG2P,TG3P,TG4P,TF1P,TF2P,TF3P,TF4P,GG,GF,OPA,PF1,  WHR01830
     XCFT,OD)                                                           WHR01840
      TG1=TG1P                                                          WHR01850
      TG2=TG2P                                                          WHR01860
      TG3=TG3P                                                          WHR01870
      TG4=TG4P                                                          WHR01880
      TF1=TF1P                                                          WHR01890
      TF2=TF2P                                                          WHR01900
      TF3=TF3P                                                          WHR01910
      TF4=TF4P                                                          WHR0192C
```

```
      GO TO 20
28    HPGTO=HPGT
C
C     CALCULATE COGAS SYSTEM OUTPUT
C
      CALL POWER(PF1,TF4,GF,DPGT,HPGT,PT,HPTO,STS,GTSFC,
     XOASFC,SFCT,GTTH,OATH,THT,ET,PCON,PHTR)
      WRITE(6,203)
203   FORMAT('0','SUMMARY OUTPUT?')
      READ(5,204) SUM
204   FORMAT(L4)
      IF(.NOT.SUM) GO TO 31
C
C     SUMMARY OUTPUT FOR THE RUN
C
      CALL OUT(SUM,HPGTO,TG1P,GG,ANTR,L,IPT,IPSA,IPB,AIH,IPSH,
     XAIB,TG3,TG4P,TF1P,TF2,TG2,TG1B1,TG1,TF4,TF3,
     XPF1,GF,DPGT,HPGT,PT,HPTO,STS,GTSFC,OASFC,SFCT,GTTH,
     XOATH,THT,SCALE,OD,ET,PCON,PHTR,REFS,REFSH,SSPD)
31    WRITE(6,200)
200   FORMAT('0','END OF DESIGN RUN.  REDESIGN?')
      READ(5,201) RED
201   FORMAT(L4)
      IF(RED) GO TO 1
40    STOP
      END
C
C
C
      SUBROUTINE HBAL(TG1,TG2,TG3,TG4,TF1,TF2,TF3,TF4,GG,GF,OPA,PF1,OPT,
     XOD)
      LOGICAL OPA,OPT,OD
      PP=25.
      TF1=200.
      IF(OPT) GO TO 2
C
C     STARTING CONDITIONS
C
      WRITE(6,300)
300   FORMAT('0','ENTER INITIAL CONDITIONS')
      WRITE(6,301)
301   FORMAT('0','TG1?')
      READ(5,302) TG1
302   FORMAT(F5.1)
      WRITE(6,303)
303   FORMAT('0','TG4?')
      READ(5,304) TG4
304   FORMAT(F5.1)
```

```
      WRITE(6,305)                                                      WHR02410
305   FORMAT('0','GAS FLOW RATE?')                                      WHR02420
      READ(5,306) GG                                                    WHR02430
306   FORMAT(F8.1)                                                      WHR02440
      TF1=200.                                                          WHR02450
      WRITE(6,307)                                                      WHR02460
307   FORMAT('0','TF4?')                                                WHR02470
      READ(5,306) TF4                                                   WHR0248C
      WRITE(6,308)                                                      WHR02490
308   FORMAT('0','PF?')                                                 WHR02500
      READ(5,309) PF1                                                   WHR02510
309   FORMAT(F5.1)                                                      WHR02520
C                                                                       WHR02530
C     CALCULATE GAS AND WATER PROPERTIES                                WHR02540
C                                                                       WHR02550
2     TGB=(TG1+TG4)/2.                                                  WHR02560
      CPG=SPECG(TGB)                                                    WHR02570
      CALL HCW(PF1,TF1,HF1)                                             WHR02580
      CALL SS(PF1,TF4,HF4,SS4,VOLF4)                                    WHR02590
C                                                                       WHR02600
C     OVERALL HEAT TRANSFER/FLUID FLOW RATE                             WHR02610
C                                                                       WHR02620
      Q=GG*CPG*(TG1-TG4)                                                WHR02630
      GF=Q/(HF4-HF1)                                                    WHR02640
C                                                                       WHR02650
C     INTERMEDIATE TEMPERATURES/HEAT TRANSFER RATES                     WHR02660
C                                                                       WHRC267C
C     SATURATOR                                                         WHR02680
C                                                                       WHR02690
5     TF2=TSL(PF1)                                                      WHR02700
      TFB1=(TF1+TF2)/2.                                                 WHR02710
      HF2=HSL(TF2)                                                      WHR02720
      QSAT=GF*(HF2-HF1)                                                 WHR02730
      CALL CPCW(PF1,TFB1,CPF1)                                          WHR02740
      TG3=(QSAT+GG*CPG*TG4)/(GG*CPG)                                    WHR02750
      QMAX=GF*CPF1*(TG3-TF1)                                            WHR02760
      EFFSA=QSAT/QMAX                                                   WHR02770
C                                                                       WHR02780
C     BCILER                                                            WHR02790
C                                                                       WHR02800
      TF3=TF2                                                           WHR02810
      CALL SS(PF1,TF3,HF3,SSS,VOL)                                      WHR02820
      QB=GF*(HF3-HF2)                                                   WHR02830
      TG2=(QB+GG*CPG*TG3)/(GG*CPG)                                      WHR02840
      QMAX=GG*CPG*(TG2-TF2)                                             WHR02850
      EFFB=QB/QMAX                                                      WHR02860
C                                                                       WHR02870
C     SUPERHEATER                                                       WHR02880
```

```
C
      CALL SS(PF1,TF4,HF4,SSS,VOL)
      QSH=GF*(HF4-HF3)
      TFB3=(TF3+TF4)/2.
      CALL CPS(PF1,TFB3,CPF3)
      QMAX=GF*CPF3*(TG1-TF3)
      EFFSH=QSH/QMAX
C
C     SET PINCH PCINT
C
      IF(OD) GO TO 10
      DIF=TG3-TF2
      IF(DIF.GE.PP) GO TO 10
      TG3=TF2+(PP+1.)
      ENRA=(HF2-HF1)/(HF4-HF1)
      TG4=(TG3-ENRA*TG1)/(1.-ENRA)
      GC TO 2
10    IF(OPA) GO TO 20
      WRITE(6,100) Q,QSAT,QB,QSH
100   FCRMAT('0','Q=',F10.1,3X,'QSAT=',F10.1,3X,'QB=',F10.1,
     X3X,'QSH=',F10.1)
      WRITE(6,110) GG,GF
110   FCRMAT('0','GG=',F8.1,3X,'GF=',F8.1)
      WRITE(6,120) TF1,TF2,TF3,TF4
120   FORMAT('0','TF1=',F5.1,3X,'TF2=',F5.1,3X,'TF3=',F5.1,3X,
     X'TF4=',F5.1)
      WRITE(6,130) TG1,TG2,TG3,TG4
130   FCRMAT('0','TG1=',F5.1,3X,'TG2=',F5.1,3X,'TG3=',F5.1,3X,
     X'TG4=',F5.1)
      WRITE(6,140) EFFSA,EFFB,EFFSH
140   FCRMAT('0','ESAT=',F4.3,3X,'EBOIL=',F4.3,3X,'ESH=',F4.3)
20    RETURN
      END
C
C
C
      SUBROUTINE OPTM(TG1P,TG1,TG4P,CS,CK,TINC)
      LOGICAL CE
      OK=1.
C
C     CHECK CURRENT GAS TEMP.IN WITH ACTUAL
C
      DIF=TG1P-TG1
      DIFA=ABS(DIF)
      IF(DIFA.LE.1.5) GO TO 15
      IF(DIFA.LE.8.) GO TO 17
5     IF(DIF.LT.0.) GO TO 10
C
```

```
C       INCREASE GAS TEMP OUT                                                WHR03370
C                                                                            WHR03380
        IF(CS.LT.0.) TINC=.5*TINC                                            WHR03390
        TG4P=TG4P+TINC                                                       WHR03400
        CS=DIF                                                               WHR03410
        GO TO 20                                                             WHR03420
C                                                                            WHR0343C
C       DECREASE GAS TEMP. OUT                                               WHR03440
C                                                                            WHR03450
10      IF(CS.GT.0.) TINC=.5*TINC                                            WHR03460
        TG4P=TG4P-TINC                                                       WHR03470
        CS=DIF                                                               WHR03480
        GO TO 20                                                             WHR03490
15      OK=0.                                                                WHR03500
        GC TO 20                                                             WHR03510
17      WRITE(6,100)                                                         WHR03520
100     FORMAT('0','CLOSE ENOUGH?')                                          WHR03530
        READ(5,110) CE                                                       WHR0354C
110     FORMAT(L4)                                                           WHR03550
        IF(CE) OK=0.                                                         WHR03560
        IF(.NOT.CE) GO TO 5                                                  WHR03570
20      RETURN                                                               WHR03580
        END                                                                  WHR0359C
C                                                                            WHR03600
C                                                                            WHR03610
C                                                                            WHR03620
        SUBROUTINE CUT(SUM,HPGTO,TG1P,GG,ANTR,L,IPT,IPSA,IPB,                WHR03630
       XAIH,IPSH,AIB,TG3,TG4P,TF1P,TF2,TG2,TGIB1,TG1,                        WHR03640
       XTF4,TF3,PF1,GF,DPGT,HPGT,PT,HPTC,STS,GTSFC,                          WHR0365C
       XOASFC,SFCT,GTTH,OATH,THT,SCALE,CD,ET,PCON,PHTR,REFS,REFSH,           WHR03660
       XSSPD)                                                                WHR03670
        IMPLICIT REAL*4(L)                                                   WHR03680
        LOGICAL SUM,OD                                                       WHR03690
        PI=3.1416                                                            WHR0370C
        CALL GEO1(ANTR,L,AMIN,DO,AFF,DI,AIP,ANTP,AOP,SN,SP,AFR,OPA           WHR03710
       X,SCALE,OPT,SUM,DTF,FPF,DFB,LTAB,FINC,AFINT,LF,TF,ANRP)               WHR03720
        HEI=(IPT*ANRP-1)*SP+DTF                                              WHR03730
        DOI=DO*12.                                                           WHR03740
        DII=DI*12.                                                           WHR03750
        FPI=FPF/12.                                                          WHR03760
        FINH=((DFB-DO)/2.+LTAB)*12.                                          WHR03770
        SNI=SN*12.                                                           WHR03780
        SPI=SP*12.                                                           WHR03790
        HL=AIH/(PI*DI*ANTR*2.)                                               WHR03800
        BL=AIB/(PI*DI*ANTP*2.)                                               WHR0381C
        P1=TG3-TF2                                                           WHR03820
        P2=TGIB1-TF2                                                         WHR03830
        PF=AMIN1(P1,P2)                                                      WHR03840
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      PCONH=2.04*PCON                                                   WHR03850
      TSAT=TSL(PFI)                                                     WHR03860
      W=AFR/L                                                           WHR03870
      GGS=GG/3600.                                                      WHR03880
      TFI=TF*12.                                                        WHR03890
      LFI=LF*12.                                                        WHR03900
      FCGT=GTSFC*HPGT                                                   WHR03910
      FCSYS=OASFC*HPTO                                                  WHR03920
      FCGTS=SFCT*HPTO                                                   WHR03930
      IF(OD) GO TO 10                                                   WHR03940
      WRITE(8,100)                                                      WHR03950
100   FORMAT('1',47X,'WASTE HEAT RECOVERY UNIT DESIGN RUN')             WHR03960
      GO TO 15                                                          WHR03970
10    WRITE(8,110)                                                      WHR03980
110   FORMAT('1',45X,'WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN')         WHR03990
15    WRITE(8,120)                                                      WHR04000
120   FORMAT(///2X,'GAS TURBINE')                                       WHR04010
      WRITE(8,130) HPGTO,SSPD                                           WHR04020
130   FORMAT('0',6X,'BRAKE HORSEPOWER:',2X,F7.1,                        WHR04030
     X',',2X,'APPROXIMATE CORRESPONDING SHIP SPEED:',2X,F4.1,2X,'KTS')  WHR04040
      WRITE(8,140) TGIP                                                 WHR04050
140   FORMAT(' ',6X,'EXHAUST GAS TEMPERATURE:',2X,F6.1,2X,'F')          WHR04060
      WRITE(8,150) GG,GGS                                               WHR04070
150   FORMAT(' ',6X,'EXHAUST GAS FLOW RATE:',2X,F8.1,2X,'LBM/HR',       WHR04080
     X2X,'(',F5.1,2X,'LBM/SEC)')                                        WHR04090
      WRITE(8,160)                                                      WHR04100
160   FORMAT(///2X,'HEAT EXCHANGER GEOMETRY')                           WHR04110
      WRITE(8,170) ANRP                                                 WHR04120
170   FORMAT('0',6X,'OVERALL DIMENSIONS:',42X,'NUMBER OF ROWS PER PASS: WHR04130
     X ',2X,F2.0)                                                       WHR04140
      WRITE(8,180) L                                                    WHR04150
180   FORMAT(' ',11X,'LENGTH:',2X,F4.1,2X,'FT.')                        WHR04160
      WRITE(8,190) W,ANTR                                               WHR04170
190   FORMAT(' ',11X,'WIDTH:',3X,F4.1,2X,'FT.',38X,'NUMBER OF TUBES PER WHR04180
     X ROW:',2X,F4.0)                                                   WHR04190
      WRITE(8,195) HEI                                                  WHR04200
195   FORMAT(' ',11X,'HEIGHT:',2X,F4.1,2X,'FT.')                        WHR04210
      WRITE(8,197) L                                                    WHR04220
197   FORMAT(' ',67X,'TUBE LENGTH',2X,F3.0,2X,'FT.')                    WHR04230
      WRITE(8,200)                                                      WHR04240
200   FORMAT(' ',6X,'HEAT TRANSFER SURFACE')                            WHR04250
      WRITE(8,210) DOI,AOP                                              WHR04260
210   FORMAT(' ',11X,'OUTSIDE TUBE DIAMETER:',2X,F4.1,2X,'IN.',         WHR04270
     X23X,'OUTSIDE AREA/PASS:',2X,F7.1,2X,'SQ.FT.')                     WHR04280
      WRITE(8,220) DII                                                  WHR04290
220   FORMAT(' ',11X,'INSIDE TUBE DIAMETER:',2X,F4.1,2X,'IN.')          WHR04300
      WRITE(8,230) AIP                                                  WHR04310
230   FORMAT(' ',11X,'TUBE/FIN ARRANGEMENT:',35X,'INSIDE AREA/PASS:',   WHR04320
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      X2X,F6.1,2X,'SQ. FT.')                                            WHR04330
       WRITE(8,240)                                                     WHR04340
240    FORMAT(' ',15X,'FIN TYPE:  SEGMENTED')                           WHR04350
       WRITE(8,250) FPI,AFR                                             WHR04360
250    FORMAT(' ',15X,'FIN SPACING:',2X,F5.2,2X,'FINS/IN.',23X,         WHR04370
      X'FRONTAL AREA:',2X,F5.1,2X,'SQ. FT.')                            WHR04380
       WRITE(8,260) LFI                                                 WHR0439C
260    FORMAT(' ',15X,'FIN HEIGHT:',2X,F3.1,2X,'IN.')                   WHR04400
       WRITE(8,270) TFI,IPT                                             WHR04410
270    FORMAT(' ',15X,'FIN THICKNESS:',2X,F5.3,2X,'IN.',26X,            WHR04420
      X'NUMBER OF PASSES:',2X,I2,2X,'(TOTAL)')                          WHR04430
       WRITE(8,280) IPSA                                                WHR0444C
280    FORMAT(' ',72X,'HEATING SECTION:',7X,I2)                         WHR04450
       WRITE(8,290) SNI,IPB,HL                                          WHR04460
290    FCRMAT(' ',6X,'TRANSVERSE TUBE SPACING:',2X,F5.2,2X,'IN.',30X,   WHR0447C
      X'BOILING SECTION:',7X,I2,3X,'(HEATING LENGTH=',1X,F4.1,1X,'FT.)') WHR04480
       WRITE(8,300) IPSH,BL                                             WHR04490
300    FORMAT(' ',72X,'SUPERHEATING SECTION:',2X,I2,3X,'(BOILING LENGTH='WHR04500
      X,1X,F4.1,1X,'FT.)')                                              WHR04510
       WRITE(8,310) SPI                                                 WHR04520
310    FORMAT(' ',6X,'LONGITUDINAL TUBE SPACING:',2X,F5.2,2X,'IN.')     WHR04530
       WRITE(8,320)                                                     WHR04540
320    FORMAT(///2X,'HEAT EXCHANGER PERFORMANCE')                       WHR0455C
       WRITE(8,330)                                                     WHR04560
330    FORMAT('0',13X,'SECTION',8X,'GAS TEMP. IN',3X,'GAS TEMP. OUT',3X, WHR04570
      X'FLUID TEMP. IN',3X,'FLUID TEMP. OUT',3X,'REYNOLDS NUMBER (AVG.)')WHR04580
       WRITE(8,340) TG3,TG4P,TF1P,TF2,REFS                              WHR04590
340    FORMAT('0',13X,'HEATING',11X,F5.1,11X,F5.1,11X,F5.1,13X,F5.1,    WHR04600
      X14X,F9.1)                                                        WHR04610
       WRITE(8,350) TG2,TG3,TF2,TF3                                     WHR04620
350    FCRMAT(' ',13X,'BOILING',11X,F5.1,11X,F5.1,11X,F5.1,13X,F5.1)    WHR04630
       WRITE(8,360) TG1,TG2,TF3,TF4,REFSH                               WHR04640
360    FORMAT(' ',13X,'SUPERHEATING',6X,F5.1,11X,F5.1,11X,F5.1,13X,F5.1, WHR04650
      X14X,F9.1)                                                        WHR0466C
       WRITE(8,370) PF1,TF3                                             WHR04670
370    FORMAT('0',6X,'STEAM PRESSURE:',2X,F5.1,2X,'PSIA',               WHR04680
      X2X,'(SATURATION TEMPERATURE=',2X,F5.1,2X,'F)')                   WHR04690
       WRITE(8,380) GF                                                  WHR04700
380    FCRMAT('0',6X,'STEAM FLOW RATE:',2X,F7.1,2X,'LBM/HR.')           WHRC4710
       WRITE(8,390) DPGT                                                WHR04720
390    FORMAT('0',6X,'GAS-SIDE PRESSURE DROP:',2X,F4.1,2X,'IN H2O')     WHR04730
       WRITE(8,400) PP                                                  WHR04740
400    FORMAT('C',6X,'PINCH POINT:',2X,F5.1,2X,'F')                     WHR04750
       WRITE(8,410)                                                     WHR04760
410    FORMAT(///2X,'SYSTEM PERFORMANCE')                               WHR04770
       WRITE(8,420) HPGT                                                WHR04780
420    FORMAT('0',6X,'GT HORSEPOWER(REVISED):',2X,F7.1,                 WHR04790
      X29X,'ASSUMED SYSTEM CHARACTERISTICS:')                           WHR04800
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      WRITE(8,430) PT,PCONH                                               WHR04810
430   FORMAT('0',6X,'STEAM TURBINE HORSEPOWER:',2X,F7.1,                  WHR04820
     X32X,'CONDENSER PRESSURE:',2X,F4.2,2X,'IN. HG')                      WHR04830
      WRITE(8,435) ET                                                     WHR04840
435   FORMAT(' ',72X,'STEAM TURBINE EFFICIENCY:',2X,F4.2)                 WHR04850
      WRITE(8,440) HPTO,PHTR                                              WHR04860
440   FORMAT(' ',6X,'TOTAL SYSTEM HORSEPOWER:',2X,F7.1,                   WHR04870
     X33X,'FW HEATER PRESSURE:',2X,F5.1,2X,'PSIA')                        WHR04880
      WRITE(8,445)                                                        WHR04890
445   FORMAT(' ',72X,'LHV OF FUEL:  18400  BTU/LBM')                      WHR04900
      WRITE(8,450) STS                                                    WHR04910
450   FORMAT(' ',6X,'STEAM TURBINE SHARE OF THE LOAD:',2X,F4.1,2X,'PERCEWHR04920
     XNT')                                                                WHR04930
      WRITE(8,460)                                                        WHR04940
460   FORMAT('0',6X,'SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):')        WHR04950
      WRITE(8,470) GTSFC,OASFC,SFCT                                       WHR04960
470   FORMAT(' ',10X,'GT ONLY:',2X,F5.3,4X,'COGAS:',2X,F5.3,4X,           WHR04970
     X'GT AT SYSTEM HP:',2X,F5.3)                                         WHR04980
      WRITE(8,475)                                                        WHR04990
475   FORMAT('0',6X,'FUEL CONSUMPTION (LBM-FUEL/HR.):')                   WHR05000
      WRITE(8,476) FCGT,FCSYS,FCGTS                                       WHR05010
476   FORMAT(' ',10X,'GT ONLY:',2X,F6.1,3X,'COGAS:',2X,F6.1,3X,           WHR05020
     X'GT AT SYSTEM HP:',2X,F6.1)                                         WHR05030
      WRITE(8,480)                                                        WHR05040
480   FORMAT('0',6X,'THERMAL EFFICIENCY:')                                WHR05050
      WRITE(8,490) GTTH,OATH,THT                                          WHR05060
490   FORMAT(' ',10X,'GT ONLY:',2X,F5.3,4X,'COGAS:',                      WHR05070
     X2X,F5.3,4X,'GT AT SYSTEM HP:',2X,F5.3)                              WHR05080
      RETURN                                                              WHR05090
      END                                                                 WHR05100
```

```
C                                                                       SATOCC1C
C       PROGRAM FOR HEATING SECTION                                     SAT00020
C                                                                       SAT00030
        SUBROUTINE SAT1(GG,GF,TGF,TGB,EFF,TF2,TFB,TCM,FG,PF,TG3,        SAT00040
       XTG4,TF1,R,TWO,GGM,LT,UF,DI,HO,OPA,SCALE,IP,CPT,ANTR,L,SUM,      SAT00050
       XREF)                                                            SAT00060
        IMPLICIT REAL*4 (L)                                             SAT00070
        LOGICAL OP,OPA,OPT,SUM                                          SAT00080
        OP=.TRUE.                                                       SAT00090
        WRITE(6,94)                                                     SAT00100
94      FORMAT('0','XXXXXXXXXX BEGIN ECONOMIZER SECTION XXXXXXXXXX')    SAT00110
        IF(OPT) GO TO 2                                                 SAT00120
        WRITE(6,85)                                                     SAT00130
85      FORMAT('0','SUPRESS OUTPUT ?')                                  SAT00140
        READ(5,86) OP                                                   SAT00150
86      FORMAT(L4)                                                      SAT00160
2       GC=4.1538E8                                                     SAT00170
        PI=3.1416                                                       SAT00180
        WRITE(6,700) TG3,TG4                                            SAT00190
700     FORMAT('0',F7.1,3X,F7.1)                                        SAT00200
        TGB=(TG3+TG4)/2.                                                SAT00210
        TGF=TGB                                                         SAT00220
        WRITE(6,90) TGF                                                 SAT00230
        TFB=(TF1+TF2)/2.                                                SAT00240
C                                                                       SAT00250
C       SATURATOR GEOMETRY                                              SAT00260
C                                                                       SAT00270
        CALL GEO1(ANTR,L,AMIN,DO,AFF,DI,AIP,ANTP,AOP,SN,SP,AFR,OPA,     SAT00280
       XSCALE,OPT,SUM,DTF,FPF,DFB,LTAB,FINC,AFINT,LF,TF,ANRP)           SAT00290
5       IF(OP) GO TO 6                                                  SAT00300
        WRITE(6,90) TGF                                                 SAT00310
90      FORMAT('0','TGF=',F7.1)                                         SAT00320
6       CALL HCW(PF,TF1,HFIN)                                           SAT00330
C                                                                       SAT00340
C       GAS SIDE REYNOLDS NUMBER (DO)                                   SAT00350
C                                                                       SAT00360
        GGM=GG/AMIN                                                     SAT00370
        VG=VISG(TGF)                                                    SAT00380
        VG=VG*.00036                                                    SAT00390
        REG=(GGM*DO)/VG                                                 SAT00400
        IF(OP) GO TO 7                                                  SAT00410
        WRITE(6,100) REG                                                SAT00420
100     FORMAT('0','REG=',F8.1)                                         SAT00430
C                                                                       SAT00440
C       GAS SIDE HEAT TRANSFER COEFFICIENT                              SAT00450
C                                                                       SAT00460
7       CALL SEGS1(REG,CJ,FG)                                           SAT00470
        IF(OP) GO TO 92                                                 SAT00480
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      WRITE(6,102) CJ,FG                                                SAT00490
102   FORMAT('0','J=',F5.4,3X,'F=',F3.2)                               SAT00500
92    PRG=PRANDG(TGF)                                                   SAT00510
      VG=VISG(TGF)*3.6E-4                                               SAT00520
      CPG=SPECG(TGF)                                                    SAT00530
      TCG=VG*CPG/PRG                                                    SAT00540
      HG=((TCG/DO)*REG*PRG**.333)*CJ                                    SAT00550
      CALL FINE(FINC,HG,AOP,AFINT,EF)                                   SAT00560
      IF(OP) GO TO 8                                                    SAT00570
      WRITE(6,105) HG                                                   SAT00580
105   FORMAT('0','HG=',F6.2)                                            SAT00590
C                                                                       SAT00600
C     FLUID SIDE REYNOLDS NUMBER                                        SAT00610
C                                                                       SAT00620
8     CALL VISCW(TFB,VF)                                                SAT00630
      VF=VF*2.778E-11                                                   SAT00640
      CALL VOLCW(PF,TFB,VOLF)                                           SAT00650
      UF=GF*VOLF/AFF                                                    SAT00660
      REF=(UF*DI)/(VOLF*VF*GC)                                          SAT00670
      IF(OP) GO TO 9                                                    SAT00680
      WRITE(6,110) REF                                                  SAT00690
110   FORMAT('0','REF=',F8.1)                                           SAT00700
C                                                                       SAT00710
C     FLUID SIDE HEAT TRANSFER COEFFICIENT                              SAT00720
C                                                                       SAT00730
9     CALL TCCW(PF,TFB,TCF)                                             SAT00740
      TCF=TCF*1E-3                                                      SAT00750
      CALL CPCW(PF,TFB,CPF)                                             SAT00760
      PRF=(VF*CPF/TCF)*GC                                               SAT00770
      HF=(.023)*(TCF/DI)*(REF**.8)*(PRF**.4)                            SAT00780
      IF(OP) GO TO 11                                                   SAT00790
      WRITE(6,120) HF                                                   SAT00800
120   FORMAT('0','HF=',F6.2)                                            SAT00810
C                                                                       SAT00820
C     OVERALL HEAT TRANSFER COEFFICIENT                                 SAT00830
C                                                                       SAT00840
11    DR=DO/DI                                                          SAT00850
      HO=1./((1./HF)+(AIP*ALOG(DR)/(2.*PI*TCM*ANTP*L))                  SAT00860
     X+(AIP/AOP)*(1./HG))                                               SAT00870
      IF(OP) GO TO 12                                                   SAT00880
      WRITE(6,130) HO                                                   SAT00890
130   FORMAT('0','HO=',F6.2)                                            SAT00900
C                                                                       SAT00910
C     PASS EFFECTIVENESS                                                SAT00920
C                                                                       SAT00930
12    CMIN=CPF*GF                                                       SAT00940
      CMAX=CPG*GG                                                       SAT00950
      C=CMIN/CMAX                                                       SAT00960
```

```
      ANTU=HO*AIP/CMIN
      SN=ANTU**(-.22)
      A=-ANTU*C*SN
      B=(EXP(A)-1.)/(C*SN)
      EFFP=1.-EXP(B)
      IF(OP) GO TO 13
      WRITE(6,140) EFFP
140   FORMAT('0','PASS EFF.=',F4.3)
C
C     SATURATOR EFFECTIVENESS/NUMBER OF PASSES REQUIRED
C)
13    ARG=(1.-EFFP*C)/(1.-EFFP)
      DO 10 N=1,15
      TF2S=TF2T
      TGIS=TGI
      EFFS=EFF
      IP=N
      EFF=(ARG**N-1.)/(ARG**N-C)
      TGI=(EFF*CMIN*TF1-CMAX*TG4)/(EFF*CMIN-CMAX)
      QL=GG*CPG*(TGI-TG4)
      HFO=HFIN+QL/GF
      TF2T=TF2-5.
      CALL TEMP1(PF,TF2T,HFO)
      IF(TF2T.GT.TF2) GO TO 15
10    CONTINUE
15    IP=IP-1
      EFF=EFFS
      TF2=TF2S
      TG3=TGIS
      R=ANRP*IP
      TAI=IP*AIP
      TAO=IP*AOP
      TGB=(TG4+TG3)/2.
      TFB=(TF1+TF2)/2.
      TWO=TGB-((HO*TAI)/(HG*TAO))*(TGB-TFB)
      IF(OP) GO TO 14
      WRITE(6,150) TWO
150   FORMAT('0','AVG. WALL TEMP.=',F7.2)
14    TGFT=(TGB+TWO)/2.
      DIFT=TGF-TGFT
      DIFA=ABS(DIFT)
      IF(DIFA.LT.10.) GO TO 20
      TGF=TGFT
      GO TO 5
600   IF(OPA) GO TO 98
20    WRITE(6,160) IP
160   FORMAT('0','NO. PASSES=',I2)
      IF(OPA) GO TO 98
```

```
      WRITE(6,165) TG3
165   FORMAT('0','REVISED GAS TEMP. IN=',F5.1)
98    LT=L*R
      HEI=SP*(R-1.)+DO
      VOLSA=HEI*AFR
      IF(OPA) GO TO 95
      WRITE(6,170) HEI,VOLSA
170   FORMAT('0','SAT. HEIGHT=',F4.1,4X,'SAT. VOLUME=',F8.2)
95    RETURN
      END
C
C
C
      SUBROUTINE SEGS1(REG,CJ,FG)
      CJ=.0396176C83718-.00334741588638*ALOG(REG)
      FG=1.08824815212-.0771218846786*ALOG(REG)
      RETURN
      END
C
C
C
      SUBROUTINE TEMP1(PF,TFO,HFO)
      TINC=10.
      DIF1=0.
40    CALL HCW(PF,TFO,HTEST)
      DIF=HFO-HTEST
      DIFA=ABS(DIF)
      IF(DIFA.LT..5) GO TO 46
      IF(DIF.LT.0.) GO TO 45
      IF(DIF1.LT.0.) TINC=.5*TINC
      TFO=TFO+TINC
      DIF1=DIF
      GO TO 40
45    IF(DIF1.GT.0.) TINC=.5*TINC
      TFO=TFO-TINC
      DIF1=DIF
      GO TO 40
46    RETURN
      END
C
C
C
      SUBROUTINE FINE(FINC,HG,AOP,AFIN,EF)
      C1=FINC*SQRT(HG)
      C1N=-C1
      TML=(EXP(C1)-EXP(C1N))/(EXP(C1)+EXP(C1N))
      EF=TML/C1
      WRITE(6,100) EF
```

```
100     FCRMAT('0','FIN EFFICIENCY=',F5.3)                                        SAT01930
        ET=1.-(1.-EF)*(AFIN/AOP)                                                  SAT01940
        HG=ET*HG                                                                  SAT01950
        RETURN                                                                    SAT01960
        END                                                                       SAT01970
```

```
C
C     PROGRAM FOR BOILING SECTION
C
      SUBROUTINE BOIL1(GG,GF,TGIN,TGOU,TFI,TFO,TFE,TGF,FG,PF,HF3,XOUT,
     XTGB,TWO,GGM,R,OPA,SCALE,IP,OPT,TGIBI,AIH,SUM)
      IMPLICIT REAL*4(L)
      LOGICAL OP,CPA,OPG,OPT,SUM
      DIMENSION QP(10),TGI(10),TGO(10),HFO(10),HFI(10),X(10),XA(10)
      OP=.TRUE.
      PI=3.1416
      GC=4.153E8
      RA=.5
      IP=1
      WRITE(6,90)
90    FORMAT('0','XXXXXXXXXX BEGIN BOILING SECTION XXXXXXXXXX')
      IF(OPT) GO TO 2
      WRITE(6,91)
91    FORMAT('0','SUPRESS OUTPUT ?')
      READ(5,92) OP
92    FORMAT(L4)
2     IF(OP) OPG=.TRUE.
C
C     BOILER GEOMETRY
C
      CALL GEO1(ANTR,L,AMIN,DO,AFF,DI,AIP,ANTP,AOP,SN,SP,AFR,OPG
     X,SCALE,OPT,SUM,DTF,FPF,DFB,LTAB,FINC,AFINT,LF,TF,ANRP)
      IF(OP) GO TO 81
      WRITE(6,80) PF,TFO
80    FORMAT('0','PF=',F5.1,3X,'TFO=',F6.2)
81    TCM=26.
      C1=.66
      A=3.4E-4
      B=6.7E3
      A1=AIP
      GFA=GF/AFF
      TBH=(TFI+TFO)/2.
      CALL CPCW(PF,TBH,CPFH)
      QF=GF*CPFH*(TFO-TFI)
      CALL TCCW(PF,TFO,TCL)
      CALL TCS(PF,TFO,TCV)
      TCL=TCL*1E-3
      TCV=TCV*1E-3
      CALL VISCW(TFO,VISL)
      CALL VISS(PF,TFO,VISV)
      VISL=VISL*2.778E-11
      VISV=VISV*2.778E-11
      CALL CPCW(PF,TFO,CPL)
      CALL CPS(PF,TFO,CPV)
```

```
      CALL SS(PF,TFO,HSV,SSS,ROV)                                        BOI00490
      CALL VOLCW(PF,TFO,VOLF)                                            BOI00500
      RCL=1./VOLF                                                        BOI0C510
      TGF=(TGIN+TGOU)/2.                                                 BOI00520
      TGO(1)=TGOU                                                        BOI00530
      HTEST=HSL(TFO)                                                     BOI00540
      HFG=HSV-HTEST                                                      BOI00550
      IF(OP) GO TC 6                                                     BOICC56C
5     WRITE(6,100) TGF                                                   BOI00570
100   FORMAT('0','TGF=',F7.1)                                            BOI00580
C                                                                        BOI00590
C     GAS SIDE REYNOLDS NUMBER                                           BOI00600
C                                                                        BOI00610
6      GGM=GG/AMIN                                                       BOI00620
      VG=VISG(TGF)                                                       BOI00630
      VG=VG*.00036                                                       BOI00640
      REG=(GGM*DO)/VG                                                    BOI00650
      IF(OP) GO TO 7                                                     BOI00660
      WRITE(6,110) REG                                                   BOI0C67C
110   FORMAT('0','REG=',F8.1)                                            BOI00680
C                                                                        BOI00690
C     GAS SIDE HEAT TRANSFER COEFFICIENT                                 BOI00700
C                                                                        BOI00710
7      CALL SEGS1(REG,CJ,FG)                                             BOI0072C
      IF(OP) GO TO 9                                                     BOI00730
      WRITE(6,120) CJ,FG                                                 BOI00740
120   FCRMAT('0','J=',F5.4,3X,'F=',F3.2)                                 BOI00750
9     PRG=PRANDG(TGF)                                                    BOI00760
      VG=VISG(TGF)*3.6E-4                                                BOI00770
      CPG=SPECG(TGF)                                                     BOI00780
      TCG=VG*CPG/PRG                                                     BOI00790
      HG=((TCG/DO)*REG*PRG**.333)*CJ                                     BOI00800
      CALL FINE(FINC,HG,AOP,AFINT,EF)                                    BOI00810
      IF(OPA) GO TO 10                                                   BOI00820
      WRITE(6,130) HG                                                    BOI0C83C
130   FORMAT('0','HG=',F6.2)                                             BOI00840
C                                                                        BOI00850
C     OVERALL HEAT TRANSFER COEFFICIENT (ROUGH, NEGLECTING INSIDE)       BOI00860
C                                                                        BOI00870
10    DR=DO/DI                                                           BOI0C88C
      HOA=1./((AIP*ALOG(DR)/(2.*PI*TCM*ANTP*L))+(AIP/AOP)*(1./HG))       BOI00890
      IF(OP) GO TO 8                                                     BOI00900
      WRITE(6,150) HOA                                                   BOI00910
150   FORMAT('0','HO(ROUGH)=',F6.2)                                      BOI00920
C                                                                        BOI00930
C     PASS EFFECTIVENESS                                                 BOI00940
C                                                                        BOI00950
8     CMIN=CPG*GG                                                        BOI00960
```

```
      ANTU=HOA*AIP/CMIN                                                 BOI00970
      EFFP=PASSB(ANTU)                                                  BOI00980
      IF(OP) GO TO 11                                                   BOI00990
      WRITE(6,160) EFFP                                                 BOI01000
160   FORMAT('0','PASS EFF.=',F4.3)                                     BOI01010
C                                                                       BOI01020
C     ROUGH GAS TEMP. INTO FIRST PASS                                   BOI01030
C                                                                       BOI01040
11    TGI(1)=(EFFP*TFI-TGO(1))/(EFFP-1.)                                BOI01050
C                                                                       BOI01060
C     ROUGH FIRST PASS HEAT TRANSFER                                    BOI01070
C                                                                       BOI01080
      QF(1)=GG*CPG*(TGI(1)-TGO(1))                                      BOI01090
C                                                                       BOI01100
C     CONDITIONS IN HEATING SECTION OF FIRST PASS                       BOI01110
C                                                                       BOI01120
      TFBH=(TFI+TFO)/2.                                                 BOI01130
      CALL CPCW(PF,TFBH,CPFH)                                           BOI01140
      CALL HCW(PF,TFI,HFIN)                                             BOI01150
      QRH=GF*(HTEST-HFIN)                                               BOI01160
      CMIN=CPFH*GF                                                      BOI01170
      CMAX=CPG*GG                                                       BOI01180
      C=CMIN/CMAX                                                       BOI01190
C                                                                       BOI01200
C     FLUID SIDE REYNOLDS NUMBER                                        BOI01210
C                                                                       BOI01220
      CALL VISCW(TFBH,VF)                                               BOI01230
      VF=VF*2.778E-11                                                   BOI01240
      CALL VOLCW(PF,TFBH,VOLF)                                          BOI01250
      UF=GF*VOLF/AFF                                                    BOI01260
      REF=(UF*DI)/(VOLF*VF*GC)                                          BOI01270
      IF(OP) GO TO 12                                                   BOI01280
      WRITE(6,183) REF                                                  BOI01290
183   FORMAT('0','REF=',F8.1)                                           BOI01300
C                                                                       BOI01310
C     FLUID SIDE HEAT TRANSFER COEFFICIENT                              BOI01320
C                                                                       BOI01330
12    CALL TCCW(PF,TFBH,TCF)                                            BOI01340
      TCF=TCF*1E-3                                                      BOI01350
      CALL CPCW(PF,TFBH,CPF)                                            BOI01360
      PRF=(VF*CPF/TCF)*GC                                               BOI01370
      HF=(.023)*(TCF/DI)*(REF**.8)*(PRF**.4)                            BOI01380
      IF(OP) GO TO 13                                                   BOI01390
      WRITE(6,184) HF                                                   BOI01400
184   FORMAT('0','HF=',F6.2)                                            BOI01410
C                                                                       BOI01420
C     OVERALL HEAT TRANSFER COEFFICIENT (HEATER)                        BOI01430
C                                                                       BOI01440
```

```
13     HOSAT=1./((1./HF)+(A1*ALOG(DR)/(2.*PI*TCM*ANTP*L))                BOI01450
      X+(AIP/AOP)*(1./HG))                                               BOI01460
19     EFFH=QRH/(CMIN*(TGI(1)-TFI))                                      BOI01470
       RA=.5                                                             BOI01480
C                                                                        BOI01490
C                                                                        BOI01500
       CMIN=CPF*GF                                                       BOI01510
       CMAX=CPG*GG                                                       BOI01520
       C=CMIN/CMAX                                                       BOI01530
       AN=HOSAT*AIP/CMIN                                                 BOI01540
       SN=AN**(-.22)                                                     BOI01550
       AA=-AN*C*SN                                                       BOI01560
       B1=(EXP(AA)-1.)/(C*SN)                                            BOI01570
       EFFP=1.-EXP(B1)                                                   BOI01580
       TGI(1)=(EFFP*CMIN*TFI-CMAX*TGO(1))/(EFFP*CMIN-CMAX)               BOI01590
       QP(1)=GG*CPG*(TGI(1)-TGO(1))                                      BOI01600
       HFO(1)=HFIN+QP(1)/GF                                              BOI01610
       X(1)=(HFO(1)-HTEST)/HFG                                           BOI01620
       AIH=((HTEST-HFIN)/(HFO(1)-HFIN))*AIP                              BOI01630
       AIH=QH/QP(1)*AIP                                                  BOI01640
       WRITE(6,190) AIH                                                  BOI01650
190    FORMAT('0','AREA FOR HEATING=',F5.1)                              BOI01660
       HO=HOSAT                                                          BOI01670
       TGIB1=TGI(1)                                                      BOI01680
       TGO(2)=TGI(1)                                                     BOI01690
       HFI(2)=HFO(1)                                                     BOI01700
       WRITE(6,188)                                                      BOI01710
188    FORMAT('0',1X,'PASS',4X,'HEAT TRANSFER',4X,'GAS TEMP IN',4X,      BOI01720
      X'ENTHALPY OUT',3X,'QUALITY',4X,'HO')                              BOI01730
       WRITE(6,189) IP,QP(1),TGI(1),HFO(1),X(1),HO                       BOI01740
189    FORMAT(' ',2X,I2,7X,F9.0,9X,F5.1,10X,F6.1,8X,F4.2,4X,F5.1)        BOI01750
C                                                                        BOI01760
C      SUBSEQUENT FLUID PASSES                                           BOI01770
C                                                                        BOI01780
39     IP=IP+1                                                           BOI01790
40     ANTU=HO*AIP/(CPG*GG)                                              BOI01800
       EFFP=PASSB(ANTU)                                                  BOI01810
       TGI(IP)=(EFFP*TFO-TGO(IP))/(EFFP-1.)                              BOI01820
       QP(IP)=(CPG*GG)*(TGI(IP)-TGO(IP))                                 BOI01830
       HFO(IP)=HFI(IP)+QP(IP)/GF                                         BOI01840
       X(IP)=(HFO(IP)-HTEST)/HFG                                         BOI01850
       IF(X(IP).GT.1.) GO TO 50                                          BOI01860
       XA(IP)=(X(IP)+X(IP-1))/2.                                         BOI01870
C                                                                        BOI01880
C      INSIDE HEAT TRANSFER COEFFICIENT                                  BOI01890
C                                                                        BOI01900
       IF(XA(IP).GT..05) GO TO 2500                                      BOI01910
       HTPF=HF                                                           BOI01920
```

```
      GO TO 3000
2500  HL=.023*(TCL/DI)*((DI*GFA/(VISL*GC))**.8)
     X*((CPL*VISL*GC)/TCL)**.4
      HTPF=(B*(1.-XA(IP))**.8)*((QP(IP)/(AIP*GFA*HFG))
     X+.001*((XA(IP)/(1.-XA(IP)))**.594))*HL
3000  HC=1./((1./HTPF)+(AIP*ALOG(DR)/(2.*PI*TCM*ANTP*L))+(AIP/AOP)*(1./H
     XG))
      ANTU=HO*AIP/(CPG*GG)
      EFFP=PASSB(ANTU)
      TGI(IP)=(EFFP*TFO-TGO(IP))/(EFFP-1.)
      QPT=(CPG*GG)*(TGI(IP)-TGO(IP))
      DIF=QP(IP)-QPT
      DIFA=ABS(DIF)
      TR=DIFA/QP(IP)
      QP(IP)=QPT
      IF(TR.GT..05) GO TO 40
      HFO(IP)=HFI(IP)+QP(IP)/GF
      X(IP)=(HFO(IP)-HTEST)/HFG
      IF(X(IP).GT.1.0007) GO TO 50
      IF(X(IP).GT.1.) X(IP)=1.
      WRITE(6,189) IP,QP(IP),TGI(IP),HFO(IP),X(IP),HC
48    HFI(IP+1)=HFO(IP)
      TGO(IP+1)=TGI(IP)
      IF(HFO(IP).LT.HSV) GO TO 39
      IF(X(IP).EQ.1.) GO TO 55
50    IP=IP-1
      HF3=HFO(IP)
      TGIN=TGI(IP)
      XOUT=X(IP)
      IF(OP) GO TO 55
      WRITE(6,240)
240   FORMAT('0','FINAL CONDITIONS OUT')
      WRITE(6,250) IP
250   FORMAT('0','NO. PASSES=',I2)
      WRITE(6,260) HF3
260   FORMAT('0','ENTHALPY OUT=',F6.1)
      WRITE(6,270) TGIN
270   FORMAT('0','GAS TEMP. IN=',F6.1)
      WRITE(6,280) XOUT
280   FORMAT('0','QUALITY OUT=',F4.2)
55    HF3=HFO(IP)
      TGIN=TGI(IP)
      XOUT=X(IP)
      R=ANRP*IP
      TAI=AIP*IP
      TAO=AOP*IP
      TFB=TFO
      TGB=(TGI(IP)+TGO(1))/2.
```

```
      TWO=TGB-((HC*TAI)/(HG*TAO))*(TGB-TFB)                             BOI02410
      IF(OP) GO TO 57                                                   BOI02420
      WRITE(6,290) TWO                                                  BOI02430
290   FORMAT('0','AVG. WALL TEMP.=',F7.2)                               BOI02440
57    TGFT=(TGB+TWO)/2.                                                 BOI02450
      DIFT=TGF-TGFT                                                     BOI02460
      DIFA=ABS(DIFT)                                                    BOI02470
      IF(DIFA.LT.50.) GO TO 60                                          BOI02480
      IP=1                                                              BOI02490
      TGF=TGFT                                                          BOI02500
      GO TO 5                                                           BOI02510
60    RETURN                                                            BOI02520
      END                                                               BOI02530
C                                                                       BOI02540
C                                                                       BOI02550
C                                                                       BOI02560
      FUNCTION PASSB(ANTU)                                              BOI02570
      PASSB=-.002641524+1.0343176*ANTU-.53877674*ANTU**2+.16522684*ANTU*BOI02580
     X*3-.027124182*ANTU**4+.0017919172*ANTU**5                         BOI02590
      RETURN                                                            BOI02600
      END                                                               BOI02610
C                                                                       BOI02620
C                                                                       BOI02630
C                                                                       BOI02640
      SUBROUTINE AREA(PF,TFI,TFO,X,AIP,AIH)                             BOI02650
      CALL VOLCW(PF,TFI,VIN)                                            BOI02660
      CALL VOLCW(PF,TFO,VSAT)                                           BOI02670
      CALL SS(PF,TFO,HSS,SSS,RSS)                                       BOI02680
      VSV=1./RSS                                                        BOI02690
      VOUT=VSAT+X*(VSV-VSAT)                                            BOI02700
      AIH=((VSAT-VIN)/(VOUT-VIN))*AIP                                   BOI02710
      RETURN                                                            BOI02720
      END                                                               BOI02730
```

```
C
C     PROGRAM FOR SUPERHEATING SECTION
C
      SUBROUTINE SUP1(GG,GF,TGIN,TGOU,TFI,TFO,FG,PF,X3,HFOLT,TGINS,
     XTGB,TWO,TGF,GGM,OPA,SCALE,IPR,IP,TGI,TF4,OPT,IPT,IPB,IPSA,
     XAIB,SUM,R,REF1)
      IMPLICIT REAL*4(L)
      LOGICAL OP,CPA,OPG,OD,OPT,SUM
      OC=.FALSE.
      IPSH=IPT-IPB-IPSA
      DIFPP=0.
      OP=.TRUE.
      IF(.NOT.OD) IPR=10
      IF(OD) LIM=IPR-1
      IF(IPR.EQ.0) GO TO 85
      PI=3.1416
      GC=4.153E8
      RA=.5
      TEST=TFO+25.
      TCM=26.
      C1=.66
      A=3.4E-4
      B=6.7E3
      TINC=10.
      IP=0
      I=0
      WRITE(6,100)
100   FORMAT('0','XXXXXXXXXX BEGIN SUPERHEATING SECTION XXXXXXXXXX')
      IF(OPT) GO TO 2
      WRITE(6,90)
90    FORMAT('0','SUPRESS OUTPUT?')
      READ(5,91) CP
91    FORMAT(L4)
      IF(OP) OPG=.TRUE.
2
C
C     SUPERHEATER GEOMETRY
C
      WRITE(6,105) TFI,PF
105   FORMAT('0','TFI=',F7.1,3X,'PF=',F6.1)
      CALL GEO1(ANTR,L,AMIN,DO,AFF,DI,AIP,ANTP,AOP,SN,SP,AFR,OPG,SCALE,
     XOPT,SUM,DTF,FPF,DFB,LTAB,FINC,AFINT,LF,TF,ANRP)
C
C
C
      DR=DO/DI
      GFA=GF/AFF
      CALL TCCW(PF,TFI,TCL)
      CALL TCS(PF,TFI,TCV)
```

```
      TCL=TCL*1E-3                                             SUP00490
      TCV=TCV*1E-3                                             SUP00500
      CALL VISCW(TFI,VISL)                                     SUP00510
      CALL VISS(PF,TFI,VISV)                                   SUP00520
      VISL=VISL*2.778E-11                                      SUP0C53C
      VISV=VISV*2.778E-11                                      SUP00540
      CALL CPCW(PF,TFI,CPL)                                    SUP00550
      CALL CPS(PF,TFI,CPV)                                     SUP00560
      CALL SS(PF,TFI,HSV,SSS,ROV)                              SUP00570
      CALL VOLCW(PF,TFI,VOLF)                                  SUP00580
      RCL=1./VOLF                                              SUP00590
      TGF=(TGIN+TGOU)/2.                                       SUP00600
      HSAT=HSL(TFI)                                            SUP00610
      HFG=HSV-HSAT                                             SUP00620
      IF(X3.GE.1.) X3=1.                                       SUP00630
      QRB=GF*((1.-X3)*HFG)                                     SUP0C64C
      XA=(1.+X3)/2.                                            SUP00650
      IF(OP) GO TO 6                                           SUP00660
5     WRITE(6,110) TGF                                         SUP00670
110   FORMAT('0','GAS FILM TEMP.=',F7.1)                       SUP00680
C                                                              SUP00690
C     GAS SIDE REYNOLDS NUMBER                                 SUP00700
C                                                              SUP00710
6     I=I+1                                                    SUP00720
      GGM=GG/AMIN                                              SUP00730
      VG=VISG(TGF)                                             SUF00740
      VG=VG*.00036                                             SUP0C75C
      REG=(GGM*DO)/VG                                          SUP00760
      IF(OP) GO TO 7                                           SUP00770
      WRITE(6,120) REG                                         SUP00780
120   FORMAT('0','REG=',F8.1)                                  SUP00790
C                                                              SUP00800
C     GAS SIDE HEAT TRANSFER COEFFICIENT                       SUP0C81C
C                                                              SUP00820
7     CALL SEGS1(REG,CJ,FG)                                    SUP00830
      IF(OP) GO TC 8                                           SUP00840
      WRITE(6,130) CJ,FG                                       SUP00850
130   FCRMAT('0','J=',F5.4,3X,'F=',F3.2)                       SUP00860
8     PRG=PRANDG(TGF)                                          SUP00870
      CPG=SPECG(TGF)                                           SUP00880
      TCG=VG*CPG/FRG                                           SUP0C890
      HG=((TCG/DO)*REG*PRG**.333)*CJ                           SUP00900
      CALL FINE(FINC,HG,AOP,AFINT,EF)                          SUP00910
      IF(X3.LT.1.) GO TO 400                                   SUP0092C
      AIB=0.                                                   SUP00930
      TGI1=TGOU                                                SUP00940
      TFO1=TFI                                                 SUP00950
      GO TO 3C0                                                SUP00960
```

```
400   IP=1                                                              SUP00970
      IF(OP) GO TO 9                                                    SUP00980
      WRITE(6,140) HG                                                   SUP00990
140   FORMAT('0','HG=',F6.2)                                            SUP01000
C                                                                       SUP01010
C     GUESS GAS TEMP. IN (FIRST PASS)                                   SUP01020
C                                                                       SUP01030
9     IF(I.GE.2) GO TO 11                                               SUP01040
      TGI1=TGOU+1.2*(QRB/(GG*CPG))                                      SUP01050
      IF(X3.LT..08) TGI1=TGOU+1.01*(QRB/(GG*CPG))                       SUP01060
      IF(X3.GT..5) TGI1=TGOU+1.5*(QRB/(GG*CPG))                         SUP01070
C                                                                       SUP01080
C     ROUGH FIRST PASS HEAT TRANSFER                                    SUP01090
C                                                                       SUP01100
11    CMINB=CPG*GG                                                      SUP01110
      QP1=CMINB*(TGI1-TGOU)                                             SUP01120
      A1=AIP                                                            SUP01130
      RAT=.1                                                            SUP01140
      IF(X3.GT..8) RAT=.15                                              SUP01150
      IF(X3.LT..1) RAT=.05                                              SUP01160
C                                                                       SUP01170
C     INSIDE HEAT TRANSFER COEFFICIENT (BOILING SECTION)                SUP01180
C                                                                       SUP01190
10    HL=.023*(TCL/DI)*((DI*GFA/(VISL*GC))**.8)                         SUP01200
     X*((CPL*VISL*GC)/TCL)**.4                                          SUP01210
      HTPF=(B*(1.-XA)**.8)*((QRB/(A1*GFA*HFG))                          SUP01220
     X+.001*((XA/(1.-XA))**.594))*HL                                    SUP01230
19    HC=1./((1./HTPF)+(A1*ALOG(DR)/(2.*PI*TCM*ANTP*L))+(AIP/AOP)*(1./H SUP01240
     XG))                                                               SUP01250
      EFFB=QRB/(CMINB*(TGI1-TFI))                                       SUP01260
C                                                                       SUP01270
C     CALCULATE AREA REQUIRED FOR BOILING                               SUP01280
C                                                                       SUP01290
      AN=HO*A1/CMINB                                                    SUP01300
      EFFT=PASSB(AN)                                                    SUP01310
      DIFPP=DIF                                                         SUP01320
      DIF=EFFT-EFFB                                                     SUP01330
      DIFA=ABS(DIF)                                                     SUP01340
      IF(DIFA.LE..01) GO TO 30                                          SUP01350
      IF(DIF.LT.0.) GO TO 20                                            SUP01360
      IF(DIFPP.LT.0.) RA=.5*RA                                          SUP01370
      A1=A1-RA*A1                                                       SUP01380
      CMINB=A1/AIP*GG*CPG                                               SUP01390
      GO TO 10                                                          SUP01400
20    IF(DIFPP.LT.0.) RA=.5*RA                                          SUP01410
      A1=A1+RA*A1                                                       SUP01420
      CMINB=A1/AIP*GG*CPG                                               SUP01430
      GO TO 10                                                          SUP01440
```

```
30    AIB=A1                                                    SUP0145C
      IF(OP) GO TO 31                                           SUP01460
      WRITE(6,185) AIB                                          SUP01470
185   FCRMAT('0','AREA REQ. FCR BOILING=',F6.2)                 SUP01480
31    QP1=GG*CPG*(TGI1-TGOU)                                    SUP01490
      QSH=QP1-QRB                                               SUP0150C
      AIS=AIP-AIB                                               SUP01510
      GGB=AIB/AIP*GG                                            SUP01520
      TGOB=TGI1-QRB/(GGB*CPG)                                   SUP01530
      GGS=GG-GGB                                                SUP01540
      IF(AIS.GT.0.) GO TO 33                                    SUP01550
      TGOS=TGI1                                                 SUP0156C
      GO TO 34                                                  SUP01570
33    TGOS=(AIP*TGOU-AIB*TGOB)/AIS                              SUP01580
34    QSH=QP1-QRB                                               SUP01590
      IF(QSH.GT.0.) GO TO 35                                    SUP01600
      TGI1=TGI1+20.                                             SUP01610
      GC TO 10                                                  SUP0162C
C                                                               SUP01630
C     SUPERHEATING SECTION OF FIRST PASS                        SUP01640
C                                                               SUP01650
C                                                               SUP01660
C     STEAM CONDITIONS (FIRST PASS)                             SUP0167C
C                                                               SUP01680
35    CALL SS(PF,TFO,HTF4,SSS,RSS)                              SUP01690
      HFO1=HSV+QSH/GF                                           SUP01700
      IF(OP) GO TC 36                                           SUP01710
      WRITE(6,188) HFO1                                         SUP01720
188   FCRMAT('0','ENTHALPY OUT OF FIRST PASS=',F6.1)            SUP0173C
C                                                               SUP01740
C     ESTIMATE FLUID TEMP. OUT (FIRST PASS)                     SUP01750
C                                                               SUP01760
36    TFO1=TFO-((HTF4-HFO1)/(HTF4-HSV))*(TFO-TFI)               SUP01770
C                                                               SUP01780
C     FIND ACTUAL FLUID TEMP. OUT                               SUP01790
C                                                               SUP01800
      CALL TEMP(PF,TFO1,HTEST,HFO1)                             SUP01810
C                                                               SUP01820
C     FLUID PRCPERTIES FOR SUPERHEATING SECTION                 SUP0183C
C                                                               SUP01840
      IF(OP) GO TO 73                                           SUP01850
46    WRITE(6,187) TFO1                                         SUP01860
187   FORMAT('0','TEMP. OUT (FIRST PASS)=',F5.1)                SUP01870
73    TFB=(TFO1+TFI)/2.                                         SUP018 8C
      CALL TCS(PF,TFB,TCS1)                                     SUP01890
      TCS1=TCS1*1E-3                                            SUP01900
      CALL SS(PF,TFB,GSS,SSS,ROS)                               SUP01910
      VOLS1=1./ROS                                              SUP01920
```

```
      CALL VISS(PF,TFB,VISI)                                            SUP01930
      VISI=VISI*2.778E-11                                               SUP01940
      CALL CPS(PF,TFB,CPS1)                                             SUP01950
C                                                                       SUP01960
C     REYNOLDS NUMBE                                                    SUP01970
C                                                                       SUP01980
      UF1=GF*VOLS1/AFF                                                  SUP01990
      REF1=(UF1*DI)/(VOLS1*VIS1*GC)                                     SUP02000
      IF(OP) GO TC 48                                                   SUP02010
      WRITE(6,190) REF1                                                 SUP02020
190   FORMAT('0','FIRST PASS RE=',F9.1)                                 SUP02030
C                                                                       SUP02040
C     FLUID SIDE HEAT TRANSFER COEFFICIENT                              SUP02050
C                                                                       SUP02060
48    PRF1=(VIS1*CPS1/TCS1)*GC                                          SUP02070
      HF1=.023*(TCS1/DI)*(REF1**.8)*(PRF1**.4)                          SUP02080
      IF(OP) GO TO 70                                                   SUP02090
      WRITE(6,200) HF1                                                  SUP02100
200   FORMAT('0','HF1=',F6.2)                                           SUP02110
C                                                                       SUP02120
C     OVERALL HEAT TRANSFER COEFFICIENT                                 SUP02130
C                                                                       SUP02140
70    DR=DO/DI                                                          SUP02150
      HO1=1./((1./HF1)+(AIS*ALOG(DR)/(2.*PI*TCM*ANTP*L))                SUP02160
     X+(AIP/AOP)*(1./HG))                                               SUP02170
      IF(OP) GO TC 49                                                   SUP02180
      WRITE(6,210) HO1                                                  SUP02190
210   FORMAT('0','HO(FIRST PASS/SH)=',F6.2)                             SUP02200
C                                                                       SUP02210
C     PASS EFFECTIVENESS                                                SUP02220
C                                                                       SUP02230
49    CMINT=CPS1*GF                                                     SUP02240
      CMAXT=CPG*GGS                                                     SUP02250
      CMIN=AMIN1(CMINT,CMAXT)                                           SUP02260
      CMAX=AMAX1(CMINT,CMAXT)                                           SUP02270
      C=CMIN/CMAX                                                       SUP02280
      ANTU=HO1*AIS/CMIN                                                 SUP02290
      SN=ANTU**(-.22)                                                   SUP02300
      AA=-ANTU*C*SN                                                     SUP02310
      BB=(EXP(AA)-1.)/(C*SN)                                            SUP02320
      EFFS=1.-EXP(BB)                                                   SUP02330
      IF(OP) GO TC 47                                                   SUP02340
      WRITE(6,220) EFFS                                                 SUP02350
220   FORMAT('0','PASS EFF. S/H SECTION=',F4.3)                         SUP02360
C                                                                       SUP02370
C     CALCULATE NEW GAS TEMP. IN                                        SUP02380
C                                                                       SUP02390
47    TGI1T=TFI+QSH/(EFFS*CMIN)                                         SUP02400
```

```
      CIFP=DIFT
      DIFPA=ABS(DIFP)
      DIFT=TGI1T-TGI1
      DIFA=ABS(DIFT)
      TR=DIFA/TGI1T
      IF(TR.LT..01) GO TO 300
      IF(DIFA.EQ.DIFPA) RAT=.75*RAT
      IF(DIFT.LT.C..AND.DIFP.LT.0.) RAT=.75*RAT
      IF(DIFT.LT.C.) TGI1=TGI1+RAT*DIFA
      IF(DIFT.GT.0..AND.DIFP.GT.0.) RAT=.75*RAT
      IF(DIFT.GT.C.) TGI1=TGI1-RAT*DIFA
      QT=GG*CPG*(TGI1-TGOU)
      IF(OP) GO TC 301
      WRITE(6,215) TGI1
215   FORMAT('0','GAS TEMP. INTO FIRST S/H PASS=',F6.1)
301   RA=.5
      GO TO 19
C
C     SUBSEQUENT PASSES
C
300   TGO2=TGI1
      TGITS=TGI1
      TFB=(TFO1+TFO)/2.
C
C     FLUID SIDE HEAT TRANSFER COEFFICIENT
C
      CALL TCS(PF,TFB,TCS2)
      TCS2=TCS2*1E-3
      CALL CPS(PF,TFB,CPS2)
      CALL VISS(PF,TFB,VIS2)
      VIS2=VIS2*2.778E-11
      CALL SS(PF,TFB,HSS,SSS,ROS)
      VOLS2=1./ROS
      UF2=GF*VOLS2/AFF
      REF2=(UF2*DI)/(VOLS2*VIS2*GC)
      IF(OP) GO TO 61
      WRITE(6,230) REF2
230   FORMAT('0','RE AFTER FIRST PASS=',F8.1)
61    PRF2=(VIS2*CPS2/TCS2)*GC
      HF2=.023*(TCS2/DI)*(REF2**.8)*(PRF2**.4)
      WRITE(6,240) HF2
240   FCRMAT('0','HF2=',F6.2)
C
C     OVERALL HEAT TRANSFER COEFFICIENT
C
62    HO=1./((1./HF2)+(AIP*ALOG(DR)/(2.*PI*TCM*ANTP*L))
     X+(AIP/AOP)*(1./HG))
      IF(OP) GO TC 63
```

```
      WRITE(6,250) HO
250   FCRMAT('0','HO=',F6.2)
C
C     PASS EFFECTIVENESS
C
63    CMIN=CPS2*GF
      CMAX=CPG*GG
      C=CMIN/CMAX
      ANTU=HO*AIP/CMIN
      SN=ANTU**(-.22)
      AA=-ANTU*C*SN
      BB=(EXP(AA)-1.)/(C*SN)
      EFFP=1.-EXP(BB)
      IF(OP) GO TC 64
      WRITE(6,260) EFFP
260   FORMAT('0','PASS EFF.=',F4.3)
C
C     SUPERHEATER EFFECTIVENESS/NUMBER OF PASSES
C
64    ARG=(1.-EFFP*C)/(1.-EFFP)
      IF(OD) GO TO 80
      IF(OPT) GO TO 500
      DO 50 N=1,8
      EFFS=EFF
      TGITS=TGI
      IP=IP+1
      EFF=(ARG**N-1.)/(ARG**N-C)
      TGI=(EFF*CMIN*TFO1-CMAX*TGO2)/(EFF*CMIN-CMAX)
      WRITE(6,295) TGI
295   FORMAT('0','TGI=',F6.1)
      IF(TGI.GT.TGIN) GC TO 55
50    CONTINUE
55    IF(IP.EQ.1) GO TO 57
      IF(IP.EQ.2..AND.X3.EQ.1.) GO TO 58
      IF(IP.EQ.2) TGITS=TGI1
58    IP=IP-1
      EFF=EFFS
      QL=GG*CPG*(TGITS-TGO2)
      HFC=HFO1+QL/GF
      TF4S=TF4
      CALL TEMP(PF,TF4S,HTEST,HFO)
      GC TO 57
56    QL=GG*CPG*(TGITS-TGO2)
      HFO=HFO1+QL/GF
      TF4S=TF4
      CALL TEMP(PF,TF4S,HTEST,HFO)
      GC TO 57
80    IF(LIM.EQ.0) GO TO 88
```

```
      ARG=(1.-EFFP*C)/(1.-EFFP)                                          SUP03370
      EFF=(ARG**LIM-1.)/(ARG**LIM-C)                                     SUP03380
      TF4=EFF*(TGIN-TF01)+TF01                                           SUP03390
      TF4S=TF4                                                           SUP03400
      IP=LIM-1                                                           SUP0341C
      GO TO 57                                                           SUP03420
500   IP=IPSH                                                            SUP03430
      N=IPSH-1                                                           SUP03440
      EFF=(ARG**N-1.)/(ARG**N-C)                                         SUP03450
      TGI=(EFF*CMIN*TF01-CMAX*TG02)/(EFF*CMIN-CMAX)                      SUP03460
      TGITS=TGI                                                          SUP03470
      QL=GG*CPG*(TGITS-TG02)                                             SUP03480
      HFC=HF01+QL/GF                                                     SUP03490
      TF4S=TF4                                                           SUP03500
      CALL TEMP(PF,TF4S,HTEST,HFO)                                       SUP03510
57    IF(IP.EQ.1) TF4S=TF01                                              SUP03520
      IF(IP.EQ.1) TGITS=TGI1                                             SUP03530
      R=2.*IP                                                            SUP03540
      TAI=IP*AIP                                                         SUP03550
      TAO=IP*AOP                                                         SUP03560
      TFB=(TFI+TF4S)/2.                                                  SUP0357C
      TGB=(TGIN+TG02)/2.                                                 SUP03580
      TWO=TGB-((HO*TAI)/(HG*TAO))*(TGB-TFB)                              SUP03590
      IF(OP) GO TO 65                                                    SUP03600
      WRITE(6,270) TWO                                                   SUP03610
270   FORMAT('0','AVG.WALL TEMP.=',F7.2)                                 SUP03620
65    TGFT=(TGB+TWO)/2.                                                  SUP03630
      DIF=TGF-TGFT                                                       SUP03640
      DIFA=ABS(DIF)                                                      SUP03650
      IF(DIFA.LT.30.) GC TO 60                                           SUP03660
      TGF=TGFT                                                           SUP03670
      IP=0                                                               SUP0368C
      GO TO 5                                                            SUP03690
67    GC TO 60                                                           SUP03700
88    TF4S=TF01                                                          SUP03710
60    WRITE(6,280) IP                                                    SUP03720
280   FORMAT('0','NO. PASSES=',I2)                                       SUP0373C
      WRITE(6,290) TF4S                                                  SUP03740
290   FORMAT('0','FLUID TEMP. OUT OF S/H=',F6.1)                         SUP03750
      WRITE(6,185) AIB                                                   SUP03760
      WRITE(6,292) TGITS                                                 SUP03770
292   FORMAT('0','GAS TEMP IN=',F6.1)                                    SUP03780
      TF4=TF4S                                                           SUP03790
      TG1=TGITS                                                          SUP03800
      R=ANRP*IP                                                          SUP03810
      GO TO 87                                                           SUP03820
85    WRITE(6,600)                                                       SUP03830
600   FORMAT('0','LAST PASS PRIOR TO SUPERHEATER')                       SUP0384C
```

```
87    RETURN                                          SUP03850
      END                                             SUP03860
C                                                     SUP03870
C                                                     SUP03880
C                                                     SUP03890
      SUBROUTINE TEMP(PF,TFO,HTEST,HFO)               SUP03900
      TINC=10.                                        SUP0391C
      DIF1=0.                                         SUP03920
40    CALL SS(PF,TFO,HTEST,SSS,RSS)                   SUP03930
      DIF=HFO-HTEST                                   SUP03940
      DIFA=ABS(DIF)                                   SUP03950
      IF(DIFA.LT..5) GO TO 46                         SUP03960
      IF(DIF.LT.0.) GO TO 45                          SUP03970
      IF(DIF1.LT.0.) TINC=.5*TINC                     SUP03980
      TFC=TFO+TINC                                    SUP03990
      DIF1=DIF                                        SUP04000
      GO TO 40                                        SUP04010
45    IF(DIF1.GT.0.) TINC=.5*TINC                     SUP04020
      TFO=TFO-TINC                                    SUP04030
      DIF1=DIF                                        SUP04040
      GC TO 40                                        SUP04050
46    RETURN                                          SUP04060
      ENC                                             SUP04070
```

```
C
C      GEOMETRY PROGRAM FOR RECTANGULAR SEGMENTED FINS
C
       SUBROUTINE GEO1(ANTR,L,AMIN,DO,AFF,DI,AIP,ANTP,AOP,SN,SP,AFR,CPA
      X,SC,OPT,SUM,DTF,FPF,DFB,LTAB,FINC,AFINT,LF,TF,ANRP)
       IMPLICIT REAL*4(L)
       LOGICAL OPA,OPT,SUM
       PI=3.1416
       IF(OPT.OR.SUM) GO TO 90
       WRITE(6,100) SC
100    FORMAT('0','SCALE=',F4.2)
       PI=3.1416
       WRITE(6,80)
80     FORMAT('0','ENTER NO. TUBES PER ROW DESIRED')
       READ(5,81) ANTR
81     FORMAT(F3.0)
       WRITE(6,82)
82     FORMAT('0','ENTER TUBE LENGTH DESIRED')
       READ(5,83) L
83     FORMAT(F3.0)
       IF(OPA) GO TO 90
       WRITE(6,84) ANTR,L
84     FORMAT('0','NO. TUBES/ROW=',F3.0,4X,'TUBE LENGTH=',F3.0)
C
C      SET DIMENSIONS
C
90     ANRP=1.
       DO=.1667*SC
       DI=.15542*SC
       TW=.01125*SC
       LF=.084583*SC
       TF=.004*SC
       TABS=38.*1
       LTAB=.0675*SC
       WTAB=.01417*SC
       DFB=.199176*SC
       FPF=71.28*(1./SC)
       SN=.375*SC
       SP=.325*SC
       TCM=26.
C
C      NUMBER OF TUBES PER PASS
C
       ANTP=ANRP*ANTR
       DTF=LF*2.+DO
C
C      FRONTAL AREA
```

```
C
      AFR=(SN*(ANTR-1.)+CTF)*L
      IF(OPA.OR.SUM) GO TO 92
      WRITE(6,85) AFR
85    FORMAT('0','FRONTAL AREA=',F6.1)
C
C     BLOCKED FRONTAL AREA
C
92    AB=ANTR*L*DO+FPF*L*ANTR*LF*2.*TF
C
C     MIN. FLOW AREA FOR GAS
C
      AMIN=AFR-AB
      IF(OPA.OR.SUM) GO TO 93
      WRITE(6,86) AMIN
86    FORMAT('0','MIN. FLOW AREA(GAS SIDE)=',F7.3)
C
C     PASS INSIDE AREA
C
93    AIP=PI*DI*L*ANTP
C
C     FIN AREA
C
      AFIN=(TABS*(2.*LTAB*WTAB+2.*TF*LTAB+WTAB*TF)
     X+(PI/2.)*(DFB**2-DO**2))*FPF*L
      AFINT=ANTP*AFIN
C
C     BARE TUBE AREA
C
      ABT=PI*DO*L-PI*DO*TF*FPF*L
C
C     PASS OUTSIDE AREA
C
      AOP=ANTP*(AFIN+ABT)
      IF(OPA.OR.SUM) GO TO 94
      WRITE(6,87) AOP,AIP
87    FORMAT('0','OUT. AREA/PASS=',F7.2,3X,'IN. AREA/PASS=',F7.3)
C
C     AREA FOR FLUID FLOW
C
94    AFF=(PI/4.)*DI**2*ANTP
C
C     GEOMETRY FOR FIN EFFICIENCY
C
      FINC=LF*((2.*(WTAB+TF)/(WTAB*TF*TCM))**.5)
      IF(OPA.OR.SUM) GO TO 120
      WRITE(6,110) FINC
110   FORMAT('0','CONST. FOR FIN EFF.=',F6.2)
```

```
  120   RETURN                                                          GE000970
        END                                                             GE000980
```

```
C
C     PROGRAM FOR COGAS SYSTEM OUTPUT
C
      SUBROUTINE POWER(PF,TSH,GF,DPGT,HPGT,PT,HPTC,STS,GTSFC,OASFC,SFC
     XT,GTTH,OATH,THT,ET,PCON,PHTR)
      IMPLICIT REAL*4(L)
      DIMENSION T(10),P(10),H(10),S(10),V(10),X(10)
      SPA=0.0
      PSF=144.
      T(1)=TSH
      P(1)=PF
      P(2)=2.
      ET=.85
      EP=.8
      X(1)=1.
      HPCNV=2544.48
      LBTU=.001285
      TFEED=200.
      HV=18400.
      PHTR=15.
      PCON=P(2)
C
C     STATE 1
C
      CALL SS(P(1),T(1),H(1),S(1),V(1))
C
C     TURBINE/CONDENSER
C
      CALL HCW(PF,TFEED,HFEED)
      S2S=S(1)
      T(2)=TSL(P(2))
      CALL HCW(PHTR,T(2),HC)
      CALL SS(P(2),T(2),H2G,S2G,V2G)
      S2F=SSL(T(2))
      X2S=(S2S-S2F)/(S2G-S2F)
      H2F=HSL(T(2))
      H2S=X2S*(H2G-H2F)+H2F
      WTS=H(1)-H2S
      WT=ET*WTS
      H(2)=H(1)-WT
      X(2)=(H(2)-H2F)/(H2G-H2F)
      FRA=(HFEED-HC)/(H(1)-HC)
      PT=((1.-FRA)*GF*WT)/HPCNV
      WRITE(6,100) PT
100   FORMAT('0','POWER OUT OF STEAM TURBINE=',F7.1)
C
C     GAS TURBINE
C
```

```
      HPR=1.0125+.002125*DPGT                                         BAL00490
      HPGT=HPGT/HPR                                                   BAL00500
      WRITE(6,150) HPGT                                               BAL00510
150   FORMAT('0','POWER OUT OF GAS TURBINE=',F8.1)                    BAL00520
      HPTO=HPGT+PT                                                    BAL00530
      WRITE(6,200) HPTO                                               BAL00540
200   FORMAT('0','TOTAL SYSTEM POWER=',F8.1)                          BAL00550
      GTSFC=SFC(HPGT)                                                 BAL00560
      SFCT=SFC(HPTO)                                                  BAL00570
      SFCF=1.006+.001*DPGT                                            BAL00580
      GTSFC=SFCF*GTSFC                                                BAL00590
      GTTH=HPCNV/(GTSFC*HV)                                           BAL00600
      GFUEL=GTSFC*HPGT                                                BAL00610
      OASFC=GFUEL/HPTO                                                BAL00620
      OATH=HPCNV/(OASFC*HV)                                           BAL00630
      THT=HPCNV/(SFCT*HV)                                             BAL00640
      WRITE(6,250) GTSFC,OASFC,HPTO,SFCT                              BAL00650
250   FORMAT('0','SFC(GT ONLY)=',F5.3,3X,'SFC(COGAS)=',F5.3,3X        BAL00660
     X,'SFC(GT AT',F7.1,2X,'HP)=',F5.3)                               BAL00670
      WRITE(6,300) GTTH,OATH                                          BAL00680
300   FORMAT('0','THERM. EFF.(GT ONLY)=',F6.4,3X,'THERM. EFF.(COGAS)=',FBAL00690
     X6.4)                                                            BAL00700
      STS=100.*(PT/HPTO)                                              BAL00710
      WRITE(6,350) STS                                                BAL00720
350   FORMAT('0','STEAM TURB. SHARE=',F5.1,2X,'PER CENT')             BAL00730
      RETURN                                                          BALCC74C
      END                                                             BAL00750
C                                                                     BAL00760
C                                                                     BAL00770
C                                                                     BAL00780
      FUNCTION SFC(HP)                                                BAL00790
      SFC=1.4954-.000335*HP+4.81953E-8*HP**2-3.6366E-12               BAL00800
     X*HP**3+1.3717E-16*HP**4-2.037E-21*HP**5                         BAL00810
      RETURN                                                          BAL00820
      END                                                             BAL00830
                                                                      BAL00840
```

```
C
C                      STEAM, WATER, AND AIR PROPERTIES
C
C          THIS SET OF SUBPRCGRAMS CALCULATES THE THERMOCYNAMIC ANC
C          TRANSPORT PROPERTIES OF STEAM, WATER, AND AIR.
C
C          INSTRUCTIONS:
C
C          1.  THE CALLING INSTRUCTIONS FOR EACH SUBPROGRAM ARE GIVEN IN
C          THE COMMENTS SECTION OF EACH SUBPROGRAM.
C          2.  ALL CALLING TEMPERATURES ARE FAHRENHEIT.
C          3.  WHERE SEPARATE SUBPROGRAMS FOR SATURATEC WATER PROPERTIES
C          ARE NOT PROVIDED, THE SUBPROGRAMS FOR COMPRESSED WATER SHCULC BE
C          USED.
C          4.  WHERE SEPARATE SUBPROGRAMS FCR SATURATEC VAPOR PROPERTIES
C          ARE NOT PROVIDED, THE SUBPROGRAM FOR SUPERHEATED STEAM SHCULD
C          BE USED.
C
C          RESTRICTIONS:
C
C          1.  WATER AND STEAM PROPERTIES:  THE SUBROUTINES FCR WATER ANC
C          STEAM PROPERTIES HAVE BEEN TESTED FOR TEMPERATURES LP TO 1000F
C          AND FOR A PRESSURE RANGE OF 1 PSIA TO 800 PSIA.  THE VALUES
C          YIELDED BY THE SUBROUTINES AGREED WITH THE VALUES IN THE
C          ASME STEAM TABLES WITHIN 1.0 PERCENT IN ALL CASES EXCEPT THE
C          STEAM TRANSPORT PROPERTIES WHERE THE ERROR WAS LESS THAN
C          3.0 PERCENT.
C          2.  AIR PROPERTIES:  THE SUBROUTINES FOR AIR PROPERTIES
C          WERE TESTED AT ATMOSPHERIC PRESSURE FOR A TEMPERATURE RANGE
C          OF 200 F TO 1500 F.  AGREEMENT TO WITHIN 5.C PERCENT OF THE
C          VALUES IN THE KEENAN AND KAYE GAS TABLES WAS OBTAINED.
C
C
C
           FUNCTION TCG(T)
C
C          TCG COMPUTES THERMAL CONDUCTIVITY (BTU/HR-FT-F) OF AIR
C          GIVEN TEMPERATURE
C
           DIMENSION A(7)
           A(1)=.012999832
           A(2)=.0000271167
           A(3)=-.0000C0012811
           A(4)=2.1052E-11
           A(5)=-3.7245E-14
           A(6)=3.5377E-17
           A(7)=-1.27737E-20
           DO 5 I=1,7
```

```
        K=I-1                                                           AUX00490
5       TCG=TCG+A(I)*T**K                                               AUX00500
        RETURN                                                          AUX00510
        END                                                             AUX00520
C                                                                       AUX00530
C                                                                       AUX00540
C                                                                       AUX00550
          FUNCTION PRANDG(T)                                            AUX00560
C                                                                       AUX00570
C       PRAND COMPUTES PRANDTL NUMBER OF AIR GIVEN TEMPERATURE          AUX00580
C                                                                       AUX0059C
        DIMENSION A(7)                                                  AUX00600
        PRANDG=0.                                                       AUX00610
        A(1)=.71905671                                                  AUX00620
        A(2)=-.CC0135162                                                AUX00630
        A(3)=-.000000091192                                             AUX0C640
        A(4)=9.5113E-10                                                 AUX00650
        A(5)=-1.56672E-12                                               AUX00660
        A(6)=1.11772E-15                                                AUX00670
        A(7)=-3.0463E-19                                                AUX00680
        CO 5 I=1,7                                                      AUX00690
        K=I-1                                                           AUX00700
5       PRANDG=PRANDG+A(I)*T**K                                         AUX00710
         RETURN                                                         AUX00720
         END                                                            AUX00730
C                                                                       AUX00740
C                                                                       AUX0C75C
C                                                                       AUX00760
          FUNCTION VISG(T)                                              AUX00770
C                                                                       AUX00780
C       VISG COMPUTES VISCOSITY ((LBM/SEC-FT)X1OE7) OF                  AUX00790
C       AIR GIVEN TEMPERATURE                                           AUX0C800
C                                                                       AUX00810
        DIMENSION A(6)                                                  AUX00820
        TR=T+459.69                                                     AUX00830
        VISG=0.                                                         AUX00840
        A(1)=-32.2839                                                   AUX00850
        A(2)=.478845                                                    AUX00860
        A(3)=-.000521402                                                AUX00870
        A(4)=.000000396954                                              AUX00880
        A(5)=-1.52477E-10                                               AUX00890
        A(6)=2.27201E-14                                                AUX00900
        DC 5 I=1,6                                                      AUX0CS1C
        K=I-1                                                           AUX00920
5       VISG=VISG+A(I)*TR**K                                            AUX00930
         RETURN                                                         AUX00940
         END                                                            AUX00950
C                                                                       AUX0C96C
```

APPENDIX B

This appendix contains the program listings for the subroutines called by the WHRU design program and the COGAS model to obtain steam, water, and air properties. References 15 and 16 provide relationships for use in calculating the thermodynamic properties of steam and water. The relationships of Ref. 15 for the thermodynamic properties of steam were used in Subroutine SS of this appendix.

The remainder of the subroutines for steam, water and air properties were obtained by fitting polynomials to the values for those properties found in References 17 and 18. In all cases, the polynomial coefficients were obtained using a "canned" program for least squares regression provided with the Hewlett-Packard System 9845 Computer installed in the Naval Postgraduate School Mechanical Engineering Department.

```
C                                                                       AUX00970
C                                                                       AUX0C98C
      FUNCTION SPECG(T)                                                 AUX00990
C                                                                       AUX01000
C     SFECG COMPUTES SPECIFIC HEAT (BTU/LBM-F) OF AIR                   AUX01010
C     GIVEN TEMPERATURE                                                 AUX01020
C                                                                       AUX01030
      DIMENSION A(6)                                                    AUX01040
      TR=T+459.69                                                       AUX01050
      SPECG=0.                                                          AUX01060
      A(1)=.2446604                                                     AUX01070
      A(2)=-.00001 7494                                                 AUX01080
      A(3)=-.000000004632                                               AUX01090
      A(4)=5.5502E-11                                                   AUX01100
      A(5)=-3.6663E-14                                                  AUX01110
      A(6)=7.1728E-18                                                   AUX01120
      DO 5 I=1,6                                                        AUX01130
      K=I-1                                                             AUX01140
    5 SPECG=SPECG+A(I)*TR**K                                            AUX01150
       RETURN                                                           AUX01160
       END                                                              AUX01170
C                                                                       AUX01180
C                                                                       AUX01190
C                                                                       AUX01200
C                                                                       AUX01210
      FUNCTION TSL(P)                                                   AUX01220
C                                                                       AUX01230
C     TSL COMPUTES SATURATICN TEMPERATURE (F)                           AUX01240
C     GIVEN PRESSURE                                                    AUX01250
C                                                                       AUX0126C
      DIMENSION A(9),B(6)                                               AUX01270
      TSL=0.                                                            AUX01280
      IF (P.LE.450.) GO TO 10                                           AUX01290
      B(1)=11545.164                                                    AUX01300
      B(2)=-8386.0182                                                   AUX01310
      B(3)=2477.7661                                                    AUX01320
      B(4)=-363.44271                                                   AUX01330
      B(5)=26.690978                                                    AUX01340
      B(6)=-.78073813                                                   AUX01350
      DO 5 I=1,6                                                        AUX01360
      J=I-1                                                             AUX0137C
      TSL=TSL+B(I)*ALOG(P)**J                                           AUX01380
    5 CONTINUE                                                          AUX01390
      GC TO 20                                                          AUX01400
   10 A(1)=35.15789                                                     AUX01410
       A(2)=24.592588                                                   AUX01420
      A(3)=2.1182069                                                    AUX01430
      A(4)=-.3414474                                                    AUX01440
```

```
      A(5)=.15741642                                    AUX01450
      A(6)=-.031329585                                  AUX01460
      A(7)=.0038658282                                  AUX01470
      A(8)=-.00C24901784                                AUX01480
      A(9)=.0000068401559                               AUX01490
      PT=P*10.                                          AUX01500
      DO 15 I=1,9                                       AUX01510
      J=I-1                                             AUX01520
15    TSL=TSL+A(I)*ALOG(PT)**J                          AUX01530
20    RETURN                                            AUX01540
      END                                               AUX01550
C                                                       AUX01560
C                                                       AUX01570
C                                                       AUX01580
      FUNCTION HSL(T)                                   AUX01590
C                                                       AUX01600
C     HSL COMPUTES ENTHALPY (BTU/LBM) OF SATURATED      AUX01610
C     WATER GIVEN TEMPERATURE                           AUX01620
C                                                       AUX01630
      DIMENSION A(6)                                    AUX01640
      HSL=0.                                            AUX01650
      IF (T.LT.360.) GO TO 5                            AUX01660
      A(1)=-9.0411706E2                                 AUX01670
      A(2)=10.673802                                    AUX01680
      A(3)=-4.2753836E-2                                AUX01690
      A(4)=9.41244E-5                                   AUX01700
      A(5)=-1.0315357E-7                                AUX01710
      A(6)=4.560246E-11                                 AUX0172C
      GO TO 10                                          AUX01730
5     A(1)=-32.179105                                   AUX01740
      A(2)=1.0088084                                    AUX01750
      A(3)=-1.1516996E-4                                AUX01760
      A(4)=4.8553836E-7                                 AUX0177C
      A(5)=-7.3618778E-10                               AUX01780
      A(6)=9.6350315E-13                                AUX01790
10    DC 15 I=1,6                                       AUX01800
      J=I-1                                             AUX01810
15    HSL=HSL+A(I)*T**J                                 AUX01820
      RETURN                                            AUX01830
      END                                               AUX01840
C                                                       AUX01850
C                                                       AUX01860
C                                                       AUX01870
      FUNCTION SSL(T)                                   AUX01880
C                                                       AUX01890
C     SSL COMPUTES ENTROPY (BTU/LBM-F) CF SATURATED     AUX01900
C     WATER GIVEN TEMPERATURE                           AUX01910
C                                                       AUX01920
```

```
      IMPLICIT REAL*4(M,N)                                          AUX01930
      DIMENSION A(8)                                                AUX01940
      SSL=0.                                                        AUX01950
      IF(T.LT.450.) GO TO 5                                         AUX01960
      M=-560.                                                       AUX01970
      N=110.                                                        AUX01980
      A(1)=.76209767                                                AUX01990
      A(2)=.13690825                                                AUX02000
      A(3)=7.5137702E-3                                             AUX02010
      A(4)=5.7828537E-3                                             AUX02020
      A(5)=-1.6168801E-3                                            AUX02030
      A(6)=-2.1403201E-3                                            AUX02040
      A(7)=3.5726534E-3                                             AUX02050
      A(8)=3.4265601E-3                                             AUX02060
      GO TO 10                                                      AUX02070
    5 M=-360.                                                       AUX02080
      N=310.                                                        AUX02090
      A(1)=.51575516                                                AUX02100
      A(2)=.39679646                                                AUX02110
      A(3)=-4.5979941E-2                                            AUX02120
      A(4)=3.4251697E-2                                             AUX02130
      A(5)=-6.072333E-3                                             AUX02140
      A(6)=-3.670358E-3                                             AUX02150
      A(7)=1.2035893E-2                                             AUX02160
      A(8)=1.234655E-2                                              AUX02170
   10 TB=(T+M)/N                                                    AUX02180
      DO 15I=1,8                                                    AUX02190
      J=I-1                                                         AUX02200
   15 SSL=SSL+A(I)*TB**J                                            AUX02210
      RETURN                                                        AUX02220
      END                                                           AUX02230
C                                                                   AUX02240
C                                                                   AUX02250
C                                                                   AUX02260
      SUBROUTINE HCW(P,T,ENTCW)                                     AUX02270
C                                                                   AUX02280
C     HCW COMPUTES ENTHALPY (BTU/LBM) OF COMPRESSED WATER           AUX02290
C     GIVEN PRESSURE AND TEMPERATURE                                AUX02300
C                                                                   AUX02310
      DIMENSION A(5),B(5,5)                                         AUX02320
      DO 5 I=1,5                                                    AUX02330
    5 A(I)=0.                                                       AUX02340
      ENTCW=0.                                                      AUX02350
      IF(P.LT.250.) GO TO 6                                         AUX02360
      B(1,1)=-3.18831669083E1                                       AUX02370
      B(1,2)=2.98504393234E-3                                       AUX02380
      B(1,3)=1.33348288125E-7                                       AUX02390
      B(1,4)=9.70260583567E-10                                      AUX02400
```

```
      B(1,5)=-1.10362284847E-12                                         AUX02410
C                                                                       AUX02420
      B(2,1)=1.00048960506                                              AUX02430
      B(2,2)=-1.05314335283E-5                                          AUX02440
      B(2,3)=1.47462503039E-8                                           AUX02450
      B(2,4)=-3.48793678207E-11                                         AUX02460
      B(2,5)=2.62881336815E-14                                          AUX02470
C                                                                       AUX02480
      B(3,1)=2.82721817375E-5                                           AUX02490
      B(3,2)=-3.12450383809E-7                                          AUX02500
      B(3,3)=9.33318841114E-10                                          AUX02510
      B(3,4)=-1.04460627415E-12                                         AUX02520
      B(3,5)=3.99352883888E-16                                          AUX02530
C                                                                       AUX02540
      B(4,1)=-1.41016204839E-6                                          AUX02550
      B(4,2)=1.11163180927E-8                                           AUX02560
      B(4,3)=-3.06157719541E-11                                         AUX02570
      B(4,4)=3.50394655357E-14                                          AUX02580
      B(4,5)=-1.43655502814E-17                                         AUX02590
C                                                                       AUX02600
      B(5,1)=4.07664360036E-10                                          AUX02610
      B(5,2)=-1.87878835824E-13                                         AUX02620
      B(5,3)=1.1016365709E-15                                           AUX02630
      B(5,4)=-2.06875806005E-18                                         AUX02640
      B(5,5)=1.2174855867E-21                                           AUX02650
      GO TO 9                                                           AUX02660
    6 IF(P.LT.15.) GO TO 8                                              AUX02670
      B(1,1)=-32.298005582                                              AUX02680
      B(1,2)=1.27073877487E-2                                           AUX02690
      B(1,3)=-1.24633564596E-4                                          AUX02700
      B(1,4)=7.14487908312E-7                                           AUX02710
      B(1,5)=-1.36503536452E-9                                          AUX02720
C                                                                       AUX02730
      B(2,1)=1.01381573376                                              AUX02740
      B(2,2)=-2.93828430308E-4                                          AUX02750
      B(2,3)=2.86589395496E-6                                           AUX02760
      B(2,4)=-1.30522857424E-8                                          AUX02770
      B(2,5)=2.11847605407E-11                                          AUX02780
C                                                                       AUX02790
      B(3,1)=-1.91102040795E-4                                          AUX02800
      B(3,2)=4.08786757295E-6                                           AUX02810
      B(3,3)=-4.09161725681E-8                                          AUX02820
      B(3,4)=1.82954852791E-10                                          AUX02830
      B(3,5)=-2.91997554328E-13                                         AUX02840
C                                                                       AUX02850
      B(4,1)=9.31823679019E-7                                           AUX02860
      B(4,2)=-2.39081198404E-8                                          AUX02870
      B(4,3)=2.47927446956E-10                                          AUX02880
```

```
      B(4,4)=-1.11965391764E-12                                          AUX02890
      B(4,5)=1.79677751792E-15                                           AUX02900
C                                                                        AUX02910
      B(5,1)=-1.37661172896E-9                                           AUX02920
      B(5,2)=4.68882864067E-11                                           AUX02930
      B(5,3)=-4.84079843213E-13                                          AUX02940
      B(5,4)=2.11882315 96E-15                                           AUX02950
      B(5,5)=-3.28078007138E-18                                          AUX02960
C                                                                        AUX02970
      GO TO 9                                                            AUX02980
C                                                                        AUX02990
8     B(1,1)=-33.9774136563                                              AUX03000
      B(1,2)=1.42585787825                                               AUX03010
      B(1,3)=-.329355699335                                              AUX03020
      B(1,4)=2.87673452024E-2                                            AUX03030
      B(1,5)=-8.42437941683E-4                                           AUX03040
C                                                                        AUX03050
      B(2,1)=1.12118345966                                               AUX03060
      B(2,2)=-8.72001344198E-2                                           AUX03070
      B(2,3)=1.99827532858E-2                                            AUX03080
      B(2,4)=-1.73328589779E-3                                           AUX03090
      B(2,5)=5.05202831066E-5                                            AUX03100
C                                                                        AUX03110
      B(3,1)=-2.65590705018E-3                                           AUX03120
      B(3,2)=1.96097311421E-3                                            AUX03130
      B(3,3)=-4.4506321979E-4                                            AUX03140
      B(3,4)=3.83467251626E-5                                            AUX03150
      B(3,5)=-1.11243809796E-6                                           AUX03160
C                                                                        AUX03170
      B(4,1)=2.55004247051E-5                                            AUX03180
      B(4,2)=-1.92085012998E-5                                           AUX03190
      B(4,3)=4.32399525838E-6                                            AUX03200
      B(4,4)=-3.70393732743E-7                                           AUX03210
      B(4,5)=1.07027718423E-8                                            AUX03220
C                                                                        AUX03230
      B(5,1)=-9.12566489903E-8                                           AUX03240
      B(5,2)=6.92372113929E-8                                            AUX03250
      B(5,3)=-1.5478901162E-8                                            AUX03260
      B(5,4)=1.31989972084E-9                                            AUX03270
      B(5,5)=-3.80217009719E-11                                          AUX03280
C                                                                        AUX03290
9     DO 10 I=1,5                                                        AUX03300
      DO 10 J=1,5                                                        AUX03310
      K=J-1                                                              AUX03320
10    A(I)=A(I)+B(I,J)*F**K                                              AUX03330
C                                                                        AUX03340
      DO 15 I=1,5                                                        AUX03350
      K=I-1                                                              AUX03360
```

```
15    ENTCW=ENTCW+A(I)*T**K                                    AUX0337C
      RETURN                                                   AUX03380
      END                                                      AUX03390
C                                                              AUX03400
C                                                              AUX03410
C                                                              AUX03420
      SLBROUTINE SCW(P,T,ENTRCW)                               AUX03430
C                                                              AUX03440
C     SCW COMPUTES ENTROPY (BTU/LBM-F) CF COMPRESSED WATER     AUX03450
C     GIVEN PRESSURE AND TEMPERATURE                           AUX03460
C                                                              AUX03470
      DIMENSION A(7)                                           AUX0348C
      DC 5 I=1,7                                               AUX03490
5     A(I)=0.                                                  AUX03500
      ENTRCW=0.                                                AUX03510
      IF(P.GT.350.) GO TO 10                                   AUX03520
      A(1)=-.06718122                                          AUX03530
      A(2)=.002177559                                          AUXC3540
      A(3)=-.00000241971                                       AUX03550
      A(4)=3.38002E-9                                          AUX03560
      A(5)=-3.4031E-12                                         AUX03570
      A(6)=2.018E-15                                           AUX03580
      DO 6 I=1,6                                               AUX0359C
      K=I-1                                                    AUX03600
6     ENTRCW=ENTRCW+A(I)*T**K                                  AUX03610
      GC TO 25                                                 AUX03620
C                                                              AUX03630
C                                                              AUX03640
10    IF(P.GT.560.) GO TO 15                                   AUX0365C
      A(1)=-.0671726                                           AUX03660
      A(2)=.002179035                                          AUX03670
      A(3)=-.0000025082                                        AUX03680
      A(4)=4.2146E-9                                           AUX03690
      A(5)=-6.909E-12                                          AUX0370C
      A(6)=8.804E-15                                           AUX03710
      A(7)=-4.888E-18                                          AUX03720
      DC 11 I=1,7                                              AUX03730
      K=I-1                                                    AUX03740
11    ENTRCW=ENTRCW+A(I)*T**K                                  AUX03750
      GO TO 25                                                 AUX03760
15    A(1)=-.0673C78                                           AUX03770
      A(2)=.002183675                                          AUX03780
      A(3)=-.0000C256749                                       AUX03790
      A(4)=4.3649E-9                                           AUX03800
      A(5)=-6.545E-12                                          AUXC381C
      A(6)=6.776E-15                                           AUX03820
      A(7)=-2.73E-18                                           AUX03830
      DO 16 I=1,7                                              AUX03840
```

```
      K=I-1                                                             AUX03850
16    ENTRCW=ENTRCW+A(I)*T**K                                           AUX03860
25    RETURN                                                            AUX03870
      END                                                               AUX03880
C                                                                       AUX03890
C                                                                       AUX03900
C                                                                       AUX03910
      SUBROUTINE TCCW(P,T,TC)                                           AUX03920
C                                                                       AUX03930
C     TCCW COMPUTES THE THERMAL CONDUCTIVITY (BTU/HR-FT-F) OF          AUX03940
C     COMPRESSED WATER GIVEN PRESSURE AND TEMPERATURE                   AUX03950
C                                                                       AUX03960
      DIMENSION A(5),B(5,4)                                             AUX03970
      DO 5 I=1,5                                                        AUX03980
5     A(I)=0.                                                           AUX03990
      TC=0.                                                             AUX04000
      IF(P.GT.10.) GO TO 10                                             AUX04010
      A(1)=307.7700899                                                  AUX04020
      A(2)=.696656122                                                   AUX04030
      A(3)=-.00141211951                                                AUX04040
      DO 6 I=1,3                                                        AUX04050
      K=I-1                                                             AUX04060
6     TC=TC+A(I)*T**K                                                   AUX04070
      GO TO 25                                                          AUX04080
C                                                                       AUX04090
10    B(1,1)=307.0877221                                                AUX04100
      B(1,2)=.007133552                                                 AUX04110
      B(1,3)=-.0001984973                                               AUX04120
      B(1,4)=1.5643034E-8                                               AUX04130
C                                                                       AUX04140
      B(2,1)=.7234487569                                                AUX04150
      B(2,2)=-.0001127153l7                                             AUX04160
      B(2,3)=6.3925874E-7                                               AUX04170
      B(2,4)=-5.0782358E-10                                             AUX04180
C                                                                       AUX04190
      B(3,1)=-.00170641C367                                             AUX04200
      B(3,2)=4.163327E-7                                                AUX04210
      B(3,3)=-3.73672272E-9                                             AUX04220
      B(3,4)=3.09641147E-12                                             AUX04230
C                                                                       AUX04240
      B(4,1)=1.0083848l1E-6                                             AUX04250
      B(4,2)=1.80385129E-9                                              AUX04260
      B(4,3)=1.46999925E-12                                             AUX04270
      B(4,4)=-2.36900054E-15                                            AUX04280
C                                                                       AUX04290
      B(5,1)=-1.286417756E-10                                           AUX04300
      B(5,2)=-6.667660057E-12                                           AUX04310
      B(5,3)=1.273196646E-14                                            AUX04320
```

```
      B(5,4)=-7.32465883E-18                                          AUX04330
C                                                                     AUX04340
      DO 15 I=1,5                                                     AUX04350
      DO 15 J=1,4                                                     AUX04360
      K=J-1                                                           AUX04370
15    A(I)=A(I)+B(I,J)*P**K                                           AUX04380
C                                                                     AUX04390
      DO 20 I=1,5                                                     AUX04400
      K=I-1                                                           AUX04410
20    TC=TC+A(I)*T**K                                                 AUX04420
25    RETURN                                                          AUX04430
      END                                                             AUX04440
C                                                                     AUX04450
C                                                                     AUX04460
C                                                                     AUX04470
      SUBROUTINE CPCW(P,T,CP)                                         AUX04480
C                                                                     AUX04490
C     CPCW COMPUTES THE SPECIFIC HEAT (BTU/LBM-F) OF                  AUX04500
C     COMPRESSED WATER GIVEN PRESSURE AND TEMPERATURE                 AUX04510
C                                                                     AUX04520
      DIMENSION A(7)                                                  AUX04530
      CP=0.                                                           AUX04540
      IF(P.GT.60.) GO TO 10                                           AUX04550
      A(1)=1.0287136                                                  AUX04560
      A(2)=-.001013384                                                AUX04570
      A(3)=.00001238154                                               AUX04580
      A(4)=-7.22385E-8                                                AUX04590
      A(5)=2.09487E-10                                                AUX04600
      A(6)=-2.29792E-13                                               AUX04610
      DO 5 I=1,6                                                      AUX04620
      K=I-1                                                           AUX04630
5     CP=CP+A(I)*T**K                                                 AUX04640
      GO TO 20                                                        AUX04650
10    A(1)=1.014979                                                   AUX04660
      A(2)=-.000548746                                                AUX04670
      A(3)=.0000058493                                                AUX04680
      A(4)=-3.07961E-8                                                AUX04690
      A(5)=9.5209E-11                                                 AUX04700
      A(6)=-1.48161E-13                                               AUX04710
      A(7)=9.692E-17                                                  AUX04720
      DO 15 I=1,7                                                     AUX04730
      K=I-1                                                           AUX04740
15    CP=CP+A(I)*T**K                                                 AUX04750
20    RETURN                                                          AUX04760
      END                                                             AUX04770
C                                                                     AUX04780
C                                                                     AUX04790
C                                                                     AUX04800
```

```
      SUBROUTINE VISCW(T,VIS)                                           AUX04810
C                                                                       AUX04820
C     VISCW COMPUTES VISCOSITY ((LBF-SEC/FT2)X10E7) OF                  AUX04830
C     COMPRESSED WATER GIVEN TEMPERATURE                                AUX04840
C                                                                       AUX04850
      DIMENSION A(8)                                                    AUX04860
      VIS=0.                                                            AUX04870
      A(1)=614.4041                                                     AUX04880
      A(2)=-10.547513                                                   AUX04890
      A(3)=.09648986                                                    AUX04900
      A(4)=-.0005260201                                                 AUX04910
      A(5)=.000001748041                                                AUX04920
      A(6)=-3.460226E-9                                                 AUX04930
      A(7)=3.74087E-12                                                  AUX04940
      A(8)=-1.697431E-15                                                AUX04950
      DO 5 I=1,8                                                        AUX04960
      K=I-1                                                             AUX04970
    5 VIS=VIS+A(I)*T**K                                                 AUX04980
      RETURN                                                            AUX04990
      END                                                               AUX05000
C                                                                       AUX05010
C                                                                       AUX05020
C                                                                       AUX05030
      SUBROUTINE VOLCW(P,T,VOL)                                         AUX05040
C                                                                       AUX05050
C     VOLCW COMPUTES SPECIFIC VOLUME (FT3/LBM) OF COMPRESSED            AUX05060
C     WATER GIVEN PRESSURE AND TEMPERATURE                              AUX05070
C                                                                       AUX05080
      DIMENSION A(7)                                                    AUX05090
      VOL=0.                                                            AUX05100
      IF(P.GT.40.) GO TO 5                                              AUX05110
      A(1)=.016055142                                                   AUX05120
      A(2)=-.0000025908                                                 AUX05130
      A(3)=.000000043087                                                AUX05140
      A(4)=-1.2311E-10                                                  AUX05150
      A(5)=2.737E-13                                                    AUX05160
      A(6)=-2.424E-16                                                   AUX05170
      DO 4 I=1,6                                                        AUX05180
      K=I-1                                                             AUX05190
    4 VOL=VOL+A(I)*T**K                                                 AUX05200
      GO TO 40                                                          AUX05210
    5 IF (P.GT.250.) GO TO 10                                           AUX05220
      A(1)=.01604542                                                    AUX05230
      A(2)=-.0000024005                                                 AUX05240
      A(3)=.000000040334                                                AUX05250
      A(4)=-1.0967E-10                                                  AUX05260
      A(5)=2.843E-13                                                    AUX05270
      A(6)=-4.747E-16                                                   AUX05280
```

```
      A(7)=4.132E-19
      DO 9 I=1,7
      K=I-1
9     VOL=VOL+A(I)*T**K
      GO TO 40
10    IF(P.GT.500.) GO TO 15
      A(1)=.01599807
      A(2)=-.COCOC10895
      A(3)=.000000023031
      A(4)=3.35E-12
      A(5)=-1.217E-13
      A(6)=2.933E-16
      A(7)=-1.748E-19
      DO 14 I=1,7
      K=I-1
14    VCL=VOL+A(I)*T**K
      GO TO 40
15    A(1)=.01600488
      A(2)=-.00COC20146
      A(3)=.000000036511
      A(4)=-8.142E-11
      A(5)=1.4081E-13
      A(6)=-1.148E-16
      A(7)=8.034E-20
      DO 16 I=1,7
      K=I-1
16    VCL=VOL+A(I)*T**K
40    RETURN
      END
C
C
C
      SUBROUTINE TCS(P,T,TC)
C
C     TCS COMPUTES THERMAL CONDUCTIVITY ((BTU/HR-FT-F)X10E3)
C     OF STEAM GIVEN PRESSURE AND TEMPERATURE
C
      DIMENSICN A(7),B(5,4)
      DO 5 I=1,5
5     A(I)=0.
      TC=0.
      IF(P.GE.50.) GO TO 15
      A(1)=9.90499
      A(2)=.0139368
      A(3)=.0000368914
      A(4)=-.0000000589
      A(5)=7.615E-11
      A(6)=-5.164E-14
```

```
      A(7)=1.3371E-17                                          AUX05770
      DO 10  I=1,7                                             AUXC578C
      K=I-1                                                    AUX05790
10    TC=TC+A(I)*T**K                                          AUX05800
      GC TO 30                                                 AUX05810
C                                                              AUX05820
15    B(1,1)=8.7550405                                         AUX05830
      B(1,2)=.096375699                                        AUXC584C
      B(1,3)=-.000054876232                                    AUX05850
      B(1,4)=4.14264051E-7                                     AUX05860
C                                                              AUX05870
      B(2,1)=.014332668                                        AUX05880
      B(2,2)=-.00042096669                                     AUX05890
      B(2,3)=2.2221582E-7                                      AUX05900
      B(2,4)=-1.92572826E-9                                    AUX05910
C                                                              AUX05920
      B(3,1)=.000043096178                                     AUX05930
      B(3,2)=6.4811772E-7                                      AUX05940
      B(3,3)=-1.5156235E-10                                    AUX05950
      B(3,4)=3.25662448E-12                                    AUX05960
C                                                              AUX05970
      B(4,1)=-4.2130659E-8                                     AUX05980
      B(4,2)=-3.7618844E-10                                    AUX05990
      B(4,3)=-2.1559946E-13                                    AUX06000
      B(4,4)=-2.35229691E-15                                   AUX06010
C                                                              AUX06020
      B(5,1)=1.77924019E-11                                    AUX06030
      B(5,2)=5.4324874E-14                                     AUX06040
      B(5,3)=2.0441744E-16                                     AUX06050
      B(5,4)=6.0458155E-19                                     AUX06060
C                                                              AUX06070
      DC 20  I=1,5                                             AUX06080
      DO 20  J=1,4                                             AUX06090
      K=J-1                                                    AUX06100
20    A(I)=A(I)+B(I,J)*F**K                                    AUX0611C
C                                                              AUX06120
      DC 25  I=1,5                                             AUX06130
      K=I-1                                                    AUX06140
25    TC=TC+A(I)*T**K                                          AUX06150
30    RETURN                                                   AUX06160
      END                                                      AUX06170
C                                                              AUX06180
C                                                              AUX06190
C                                                              AUX06200
      SUBROUTINE VISS(P,T,VIS)                                 AUX06210
C                                                              AUX06220
C     VISS COMPUTES VISCOSITY ((LBF-SEC/FT2)X10E7) OF          AUX06230
C     STEAM GIVEN TEMPERATURE                                  AUX06240
```

```
C                                                                     AUX06250
      DIMENSION A(7)                                                  AUX06260
      VIS=0.                                                          AUX06270
      IF(P.GE.50.) GO TC 10                                           AUX06280
      A(1)=1.926629                                                   AUX06290
      A(2)=.0002555                                                   AUX0630C
      A(3)=.0000208279                                                AUX06310
      A(4)=-.000000049502                                             AUX06320
      A(5)=6.3081E-11                                                 AUX06330
      A(6)=-4.0799E-14                                                AUX06340
      A(7)=1.05411E-17                                                AUX06350
      DO 5 I=1,7                                                      AUX06360
      K=I-1                                                           AUX06370
5     VIS=VIS+A(I)*T**K                                               AUX06380
      GO TO 20                                                        AUX06390
10    A(1)=5.72541                                                    AUX06400
      A(2)=-.0332628                                                  AUX06410
      A(3)=.00012E7352                                                AUX06420
      A(4)=-2.088647E-7                                               AUX06430
      A(5)=1.636259E-10                                               AUX06440
      A(6)=-4.96576E-14                                               AUX06450
      DC 15 I=1,6                                                     AUX0646C
      K=I-1                                                           AUX06470
15    VIS=VIS+A(I)*T**K                                               AUX06480
20    RETURN                                                          AUX06490
      END                                                             AUX06500
C)                                                                    AUX06510
C                                                                     AUX06520
C                                                                     AUX06530
      SUBROUTINE CPS(P,T,CP)                                          AUX06540
C                                                                     AUX06550
C     CPS COMPUTES SPECIFIC HEAT (BTU/LBM-F) OF                       AUX06560
C     STEAM GIVEN PRESSURE AND TEMPERATURE                            AUX0657C
C                                                                     AUX06580
      DIMENSION A(7),B(7,5)                                           AUX06590
      DC 5 I=1,7                                                      AUX06600
5     A(I)=0.                                                         AUX06610
      CP=0.                                                           AUX06620
      IF(P.GE.10.) GO TO 16                                           AUX0663C
C                                                                     AUX06640
      B(1,1)=.422296265                                               AUX06650
      B(1,2)=.030268522                                               AUX06660
      B(1,3)=-.004854928                                              AUX06670
      B(1,4)=-.0000059748                                             AUX0668C
      B(1,5)=.0000445136                                              AUX06690
C                                                                     AUX06700
      B(2,1)=.000181043581                                            AUX06710
      B(2,2)=-.00C17032551 7                                          AUX06720
```

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      B(2,3)=-.000013866942                                             AUX06730
      B(2,4)=1.37436147E-5                                              AUX06740
      B(2,5)=-1.38328347E-6                                             AUX06750
C                                                                       AUX06760
      B(3,1)=-1.6226512E-7                                              AUX06770
      B(3,2)=-1.3626817E-7                                              AUX06780
      B(3,3)=4.8500908E-7                                               AUX06790
      B(3,4)=-1.4264727E-7                                              AUX06800
      B(3,5)=1.12507264E-8                                              AUX06810
C                                                                       AUX06820
      B(4,1)=-5.6930996E-10                                             AUX06830
      B(4,2)=2.50520512E-9                                              AUX06840
      B(4,3)=-2.19632537E-9                                             AUX06850
      B(4,4)=5.31864156E-10                                             AUX06860
      B(4,5)=-3.83612442E-11                                            AUX06870
C                                                                       AUX06880
      B(5,1)=1.9550162513E-12                                           AUX06890
      B(5,2)=-5.8231567039E-12                                          AUX06900
      B(5,3)=4.10144879154E-12                                          AUX06910
      B(5,4)=-9.18383604222E-13                                         AUX06920
      B(5,5)=6.33208744846E-14                                          AUX06930
C                                                                       AUX06940
      B(6,1)=-2.01614243525E-15                                         AUX06950
      B(6,2)=5.38727678341E-15                                          AUX06960
      B(6,3)=-3.47742978501E-15                                         AUX06970
      B(6,4)=7.47260528987E-16                                          AUX06980
      B(6,5)=-5.01661911137E-17                                         AUX06990
C                                                                       AUX07000
      B(7,1)=7.02997694396E-19                                          AUX07010
      B(7,2)=-1.79132736742E-18                                         AUX07020
      B(7,3)=1.10536956813E-18                                          AUX07030
      B(7,4)=-2.31734765803E-19                                         AUX07040
      B(7,5)=1.52893617959E-20                                          AUX07050
C                                                                       AUX07060
      DO 10 I=1,7                                                       AUX07070
      DO 10 J=1,5                                                       AUX07080
      K=J-1                                                             AUX07090
   10 A(I)=A(I)+B(I,J)*P**K                                             AUX07100
      DO 15 I=1,7                                                       AUX07110
      K=I-1                                                             AUX07120
   15 CP=CP+A(I)*T**K                                                   AUX07130
      GO TO 40                                                          AUX07140
C                                                                       AUX07150
   16 IF(P.GT.150.) GO TO 26                                            AUX07160
C                                                                       AUX07170
      B(1,1)=.471051822                                                 AUX07180
      B(1,2)=.0071901422                                                AUX07190
      B(1,3)=.00002902186                                               AUX07200
```

```
      B(1,4)=-1.0947953E-8                                           AUX07210
C                                                                    AUX07220
      B(2,1)=-.00030842028                                           AUX07230
      B(2,2)=-3.30841469E-5                                          AUX07240
      B(2,3)=-2.56142116E-7                                          AUX07250
      B(2,4)=4.0736494E-10                                           AUX07260
C                                                                    AUX07270
      B(3,1)=1.40514276E-6                                           AUX07280
      B(3,2)=5.510352E-8                                             AUX07290
      B(3,3)=9.0367755E-10                                           AUX07300
      B(3,4)=-2.13368295E-12                                         AUX07310
C                                                                    AUX07320
      B(4,1)=-2.3995704E-9                                           AUX07330
      B(4,2)=-3.3266941E-11                                          AUX07340
      B(4,3)=-1.54501998E-12                                         AUX07350
      B(4,4)=4.3756116E-15                                           AUX07360
C                                                                    AUX07370
      B(5,1)=1.95901818E-12                                          AUX07380
      B(5,2)=-2.753866E-15                                           AUX07390
      B(5,3)=1.26930177E-15                                          AUX07400
      B(5,4)=-3.9664668E-18                                          AUX07410
C                                                                    AUX07420
      B(6,1)=-6.16157702E-16                                         AUX07430
      B(6,2)=7.0953059E-18                                           AUX07440
      B(6,3)=-4.0450706E-19                                          AUX07450
      B(6,4)=1.34272907E-21                                          AUX07460
C                                                                    AUX07470
      DO 20 I=1,6                                                    AUX07480
      DO 20 J=1,4                                                    AUX07490
      K=J-1                                                          AUX07500
20    A(I)=A(I)+B(I,J)*P**K                                          AUX07510
C                                                                    AUX07520
      DO 25 I=1,6                                                    AUX07530
      K=I-1                                                          AUX07540
25    CP=CP+A(I)*T**K                                                AUX07550
      GO TO 40                                                       AUX07560
C                                                                    AUX07570
26    B(1,1)=-3.1654004                                              AUX07580
      B(1,2)=.050468168                                              AUX07590
      B(1,3)=-.000157021974                                          AUX07600
      B(1,4)=2.3169283E-7                                            AUX07610
      B(1,5)=-9.7309759E-11                                          AUX07620
C                                                                    AUX07630
      B(2,1)=.01818816                                               AUX07640
      B(2,2)=-.00025378215                                           AUX07650
      B(2,3)=8.1211789E-7                                            AUX07660
      B(2,4)=-1.19184066E-9                                          AUX07670
      B(2,5)=5.0417466E-13                                           AUX07680
```

```
C                                                                       AUX07690
      B(3,1)=-.000033784538                                             AUX07700
      B(3,2)=4.7562105E-7                                               AUX07710
      B(3,3)=-1.55257254E-9                                             AUX07720
      B(3,4)=2.27009037E-12                                             AUX07730
      B(3,5)=-9.6702875E-16                                             AUX07740
C                                                                       AUX07750
      B(4,1)=2.7766181E-8                                               AUX07760
      B(4,2)=-3.9361743E-10                                             AUX07770
      B(4,3)=1.30491831E-12                                             AUX07780
      B(4,4)=-1.9040844E-15                                             AUX07790
      B(4,5)=8.1631412E-19                                              AUX07800
C                                                                       AUX07810
      B(5,1)=-8.4927264E-12                                             AUX07820
      B(5,2)=1.21404264E-13                                             AUX07830
      B(5,3)=-4.0761977E-16                                             AUX07840
      B(5,4)=5.9420773E-19                                              AUX07850
      B(5,5)=-2.5627204E-22                                             AUX07860
C                                                                       AUX07870
      DO 30 I=1,5                                                       AUX07880
      DO 30 J=1,5                                                       AUX07890
      K=J-1                                                             AUX07900
   30 A(I)=A(I)+B(I,J)*P**K                                             AUX07910
      DO 35 I=1,5                                                       AUX07920
      K=I-1                                                             AUX07930
   35 CP=CP+A(I)*T**K                                                   AUX07940
   40 RETURN                                                            AUX07950
      END                                                               AUX07960
C                                                                       AUX07970
C                                                                       AUX07980
C                                                                       AUX07990
      SUBROUTINE SS(PA,TF,HSS,SSS,RSS)                                  AUX08000
C                                                                       AUX08010
C     SS COMPUTES ENTHALPY (BTU/LBM), ENTROPY (BTU/LBM-F),              AUX08020
C     AND DENSITY (FT3/LBM) OF STEAM GIVEN PRESSURE                    AUX08030
C     AND TEMPERATURE                                                   AUX08040
C                                                                       AUX08050
      T=TF/1.8+255.38                                                   AUX08060
      P=PA/14.6959                                                      AUX08070
      B1 =(2641.62/T)*10.**(80870./T**2)                                AUX08080
      B2=82.546                                                         AUX08090
      B3=162460./T                                                      AUX08100
      B4=.21828*T                                                       AUX08110
      B5=126970./T                                                      AUX08120
      B0=1.89-B1                                                        AUX08130
      FC=1.89-B1*(372420./T**2+2)                                       AUX08140
      F=775.596+.63296*T+.000162467*T**2+47.3635*ALOG10(T)              AUX08150
      B6=B0*B3-2.*F0*(B2-B3)                                            AUX08160
```

```
      B7=2.*FC*(B4-B5)-B0*B5
      B=E0*(1.+((B0*P)/T**2)*(B2-B3+((B0*P)/T**2)*(B4-B5)*BC*P))
      BET=(1./T)*((B0-F0)*P+((B0/2.)*(P/T)**2)*(B6+((B0/2.)*(P/T)**2)*B0
     X*(B0*(B4-B5)-2.*B7)))
      VCL=.0160185*((4.55504*T)/P+B)
      RSS=1./VOL
      HSS=F+.043557*(F0*P+((B0/2.)*(P/T)**2)*(-B6+B0*(B2-B3+2.*B7*(B0/2.
     X)*(P/T)**2)))
      SSS=.809691*ALOG1C(T)-.253801*ALCG10(P)+.00C18052*T-11.4276/T-
     X.355579-.0241983*BET
      RETURN
      END
```

AD-A078 154 NAVAL POSTGRADUATE SCHOOL MONTEREY CA F/G 13/10
WASTE HEAT RECOVERY UNIT DESIGN FOR GAS TURBINE PROPULSION SYST--ETC(U)
SEP 79 R M COMBS
UNCLASSIFIED NL

3 OF 4
ADA
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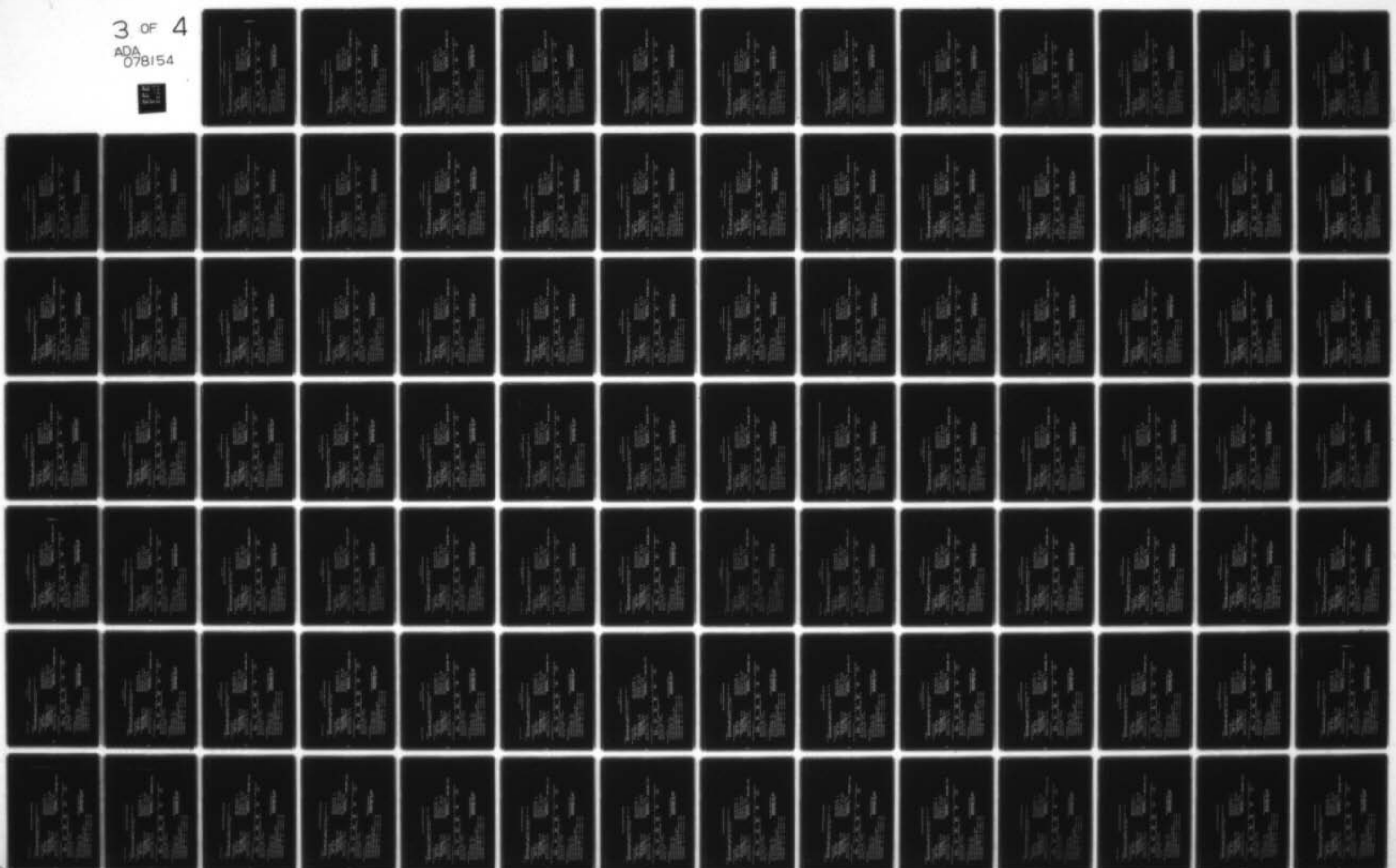

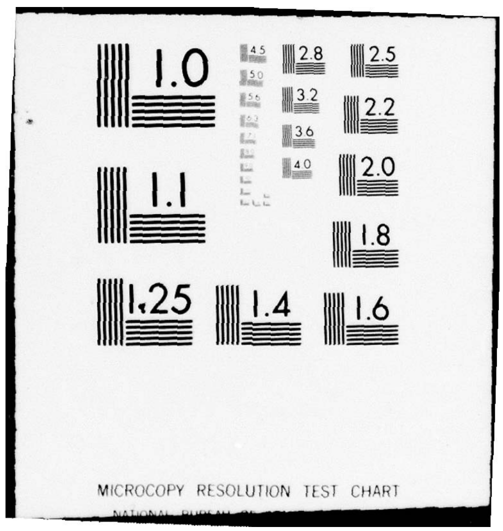
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1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
MICROCOPY RESOLUTION TEST CHART

RUN #1

08/17/79 10.42.30

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 6.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 21 (TOTAL)
HEATING SECTION: 9
BOILING SECTION: 10 (HEATING LENGTH= 3.1 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.2 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	544.7	415.0	200.0	512.7	27700.6
BOILING	781.9	544.7	512.7	518.3	
SUPERHEATING	849.0	781.9	518.3	650.0	213652.1

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 35123.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 7.8 IN H2O

PINCH POINT: 32.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 15957.2

STEAM TURBINE HORSEPOWER: 5205.2

TOTAL SYSTEM HORSEPOWER: 21162.3

STEAM TURBINE SHARE OF THE LOAD: 24.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.438 COGAS: 0.330 GT AT SYSTEM HP: 0.390

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6984.7 COGAS: 6984.7 GT AT SYSTEM HP: 8252.2

THERMAL EFFICIENCY:
GT ONLY: 0.316 COGAS: 0.419 GT AT SYSTEM HP: 0.355

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN # 2

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 4.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 15 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 8 (HEATING LENGTH= 3.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 0.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	545.7	464.4	200.0	508.9	14149.9
BOILING	715.2	545.7	508.9	518.3	
SUPERHEATING	742.1	715.2	518.3	641.3	108756.9

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 20105.6 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.7 IN H2O

PINCH POINT: 36.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8356.1

STEAM TURBINE HORSEPOWER: 2656.5

TOTAL SYSTEM HORSEPOWER: 11012.6

STEAM TURBINE SHARE OF THE LOAD: 24.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.402 GT AT SYSTEM HP: 0.482

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4431.8 COGAS: 4431.8 GT AT SYSTEM HP: 5305.8

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.344 GT AT SYSTEM HP: 0.287

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #3

08/13/76 11.52.26

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 3.6 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 11 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 4.0 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	541.6	483.0	200.0	502.0	5039.6
BOILING	530.2	541.6	502.0	518.3	
SUPERHEATING	687.6	630.2	518.3	640.0	40286.1

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7236.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.8 IN H2O

PINCH POINT: 39.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.5

STEAM TURBINE HORSEPOWER: 955.2

TOTAL SYSTEM HORSEPOWER: 2615.7

STEAM TURBINE SHARE OF THE LOAD: 36.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.064 COGAS: 0.675 GT AT SYSTEM HP: 0.890

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.0 COGAS: 1766.0 GT AT SYSTEM HP: 2327.9

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.205 GT AT SYSTEM HP: 0.155

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #4

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.39 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 16 (TOTAL)
HEATING SECTION: 7
BOILING SECTION: 7 (HEATING LENGTH= 0.0 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	551.2	421.0	200.0	518.3	27356.4
BOILING	743.9	551.2	518.3	518.3	
SUPERHEATING	348.3	743.9	518.3	641.3	213359.1

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 38597.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 6.0 IN H2O

PINCH POINT: 32.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16016.4

STEAM TURBINE HORSEPOWER: 5099.7

TOTAL SYSTEM HORSEPOWER: 21116.1

STEAM TURBINE SHARE OF THE LOAD: 24.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.437 COGAS: 0.331 GT AT SYSTEM HP: 0.391

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6992.7 COGAS: 6992.7 GT AT SYSTEM HP: 8257.0

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.418 GT AT SYSTEM HP: 0.354

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #5

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.33 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3250.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 2.1 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	547.5	465.9	200.0	511.4	14023.8
BOILING	682.5	547.5	511.4	518.3	
SUPERHEATING	740.6	682.5	518.3	635.0	109056.4

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 19998.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.1 IN H2O

PINCH POINT: 30.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8366.4

STEAM TURBINE HORSEPOWER: 2629.1

TOTAL SYSTEM HORSEPOWER: 10995.6

STEAM TURBINE SHARE OF THE LOAD: 23.9 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.403 GT AT SYSTEM HP: 0.482

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4432.5 COGAS: 4432.5 GT AT SYSTEM HP: 5300.1

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.343 GT AT SYSTEM HP: 0.287

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #6

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 5 (HEATING LENGTH= 5.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.2 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	537.5	482.5	200.0	484.5	4874.5
BOILING	658.1	537.5	484.5	518.3	
SUPERHEATING	688.5	658.1	518.3	646.3	38748.0

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7253.1 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

PINCH POINT: 53.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.9

STEAM TURBINE HORSEPOWER: 962.1

TOTAL SYSTEM HORSEPOWER: 2623.1

STEAM TURBINE SHARE OF THE LOAD: 36.7 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.673 GT AT SYSTEM HP: 0.889

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.1 COGAS: 1766.1 GT AT SYSTEM HP: 2331.6

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.205 GT AT SYSTEM HP: 0.156

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #7

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.C FT.
HEIGHT: 2.1 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 7 (HEATING LENGTH= 4.5 FT.)
SUPERHEATING SECTION: 1 (BOILING LENGTH= C.2 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	540.5	414.2	200.0	504.5	27409.0
BOILING	809.1	540.5	504.5	518.3	
SUPERHEATING	853.5	809.1	518.3	653.1	203528.9

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 39189.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 5.3 IN H2O

PINCH POINT: 36.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16040.5

STEAM TURBINE HORSEPOWER: 5226.6

TOTAL SYSTEM HORSEPOWER: 21267.1

STEAM TURBINE SHARE OF THE LOAD: 24.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.329 GT AT SYSTEM HP: 0.387

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6995.9 COGAS: 6995.9 GT AT SYSTEM HP: 8238.4

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.420 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #8

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 9526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 4 (HEATING LENGTH= 1.3 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.6 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	549.4	467.4	200.0	514.5	14117.1
BOILING	649.5	549.4	514.5	518.3	
SUPERHEATING	740.8	649.5	518.3	638.8	111551.0

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 15892.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.5 IN H2O

PINCH POINT: 34.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8376.2

STEAM TURBINE HORSEPOWER: 2623.0

TOTAL SYSTEM HORSEPOWER: 10999.1

STEAM TURBINE SHARE OF THE LOAD: 23.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.527 COGAS: 0.403 GT AT SYSTEM HP: 0.482

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4433.9 COGAS: 4433.9 GT AT SYSTEM HP: 5301.3

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.343 GT AT SYSTEM HP: 0.287

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #9

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

RATED HORSEPOWER: 1084.0, APPROXIMATE CORRESPONDING SHIP SPEED: 5.0 KTS
EXHAUST GAS TEMPERATURE: [illegible]89.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 1.1 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE ARRANGEMENT:
[illegible]: STAGGERED
FIN SPACING: 11.84 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 7 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 3 (HEATING LENGTH= 1.3 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.[illegible] FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	543.6	482.5	200.0	512.7	5135.4
BOILING	612.1	543.6	512.7	518.3	
SUPERHEATING	687.7	612.1	518.3	636.3	40228.0

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7253.1 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.5 IN H2O

PINCH POINT: 30.9 F

SYSTEM PERFORMANCE

GT NET HP (DERATED): 1061.4

STEAM TURBINE HORSEPOWER: 954.5

TOTAL SYSTEM HORSEPOWER: 2015.9

STEAM TURBINE SHARE OF THE LOAD: 36.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: [illegible] COGAS: 0.675 GT AT SYSTEM HP: 0.890

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.2 COGAS: 1766.2 GT AT SYSTEM HP: 2328.0

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.205 GT AT SYSTEM HP: 0.155

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #10

08/22/79 12.18.18

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 6.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 19 (TOTAL)
HEATING SECTION: 8
BOILING SECTION: 9 (HEATING LENGTH= 0.0 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	523.5	404.5	200.0	486.3	26712.4
BOILING	773.3	523.5	486.3	486.3	
SUPERHEATING	846.9	773.3	486.3	631.3	224206.2

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 39498.7 LBM/HR.

GAS-SIDE PRESSURE DROP: 6.7 IN H2O

PINCH POINT: 37.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 15993.3

STEAM TURBINE HORSEPOWER: 5072.3

TOTAL SYSTEM HORSEPOWER: 21065.6

STEAM TURBINE SHARE OF THE LOAD: 24.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.437 COGAS: 0.332 GT AT SYSTEM HP: 0.392

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6989.5 COGAS: 6989.5 GT AT SYSTEM HP: 8261.2

THERMAL EFFICIENCY:
GT ONLY: 0.316 COGAS: 0.417 GT AT SYSTEM HP: 0.353

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #11

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 5.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 17 (TOTAL)
HEATING SECTION: 6
BOILING SECTION: 8 (HEATING LENGTH= 0.0 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	513.4	430.5	200.0	486.3	15018.2
BOILING	666.9	513.4	486.3	486.3	
SUPERHEATING	740.7	666.9	486.3	636.3	129121.1

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 22206.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.1 IN H2O

PINCH POINT: 27.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8349.2

STEAM TURBINE HORSEPOWER: 2862.3

TOTAL SYSTEM HORSEPOWER: 11211.4

STEAM TURBINE SHARE OF THE LOAD: 25.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.531 COGAS: 0.395 GT AT SYSTEM HP: 0.479

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4431.1 COGAS: 4431.1 GT AT SYSTEM HP: 5371.5

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.350 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #12

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 3.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 4.9 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 2.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	508.1	449.4	200.0	466.3	5426.1
BOILING	643.2	508.1	466.3	486.3	
SUPERHEATING	688.0	643.2	486.3	642.5	47057.9

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8286.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.8 IN H2O

PINCH POINT: 41.3 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.4

STEAM TURBINE HORSEPOWER: 1072.9

TOTAL SYSTEM HORSEPOWER: 2733.3

STEAM TURBINE SHARE OF THE LOAD: 39.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.064 COGAS: 0.646 GT AT SYSTEM HP: 0.873

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.0 COGAS: 1766.0 GT AT SYSTEM HP: 2385.9

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.214 GT AT SYSTEM HP: 0.158

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #13

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08/22/75 12.40.51

                         WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

     BRAKE HORSEPOWER:  16421.0,  APPROXIMATE CORRESPONDING SHIP SPEED:  20.0  KTS
     EXHAUST GAS TEMPERATURE:   849.0  F
     EXHAUST GAS FLOW RATE:  407589.0  LBM/HR  (113.2  LBM/SEC)

HEAT EXCHANGER GEOMETRY

     OVERALL DIMENSIONS:                              NUMBER OF ROWS PER PASS:    1.
          LENGTH:  12.0  FT.
          WIDTH:   12.1  FT.                          NUMBER OF TUBES PER  ROW:   43.
          HEIGHT:   3.7  FT.
                                                      TUBE LENGTH  12.  FT.
     HEAT TRANSFER SURFACE
          OUTSIDE TUBE DIAMETER:    1.5  IN.          OUTSIDE AREA/PASS:   3290.5  SQ.FT.
          INSIDE TUBE DIAMETER:   1.4  IN.
          TUBE/FIN ARRANGEMENT:                       INSIDE AREA/PASS:   189.0  SQ. FT.
               FIN TYPE:  SEGMENTED
               FIN SPACING:    7.92  FINS/IN.         FRONTAL AREA:  144.8  SQ. FT.
               FIN HEIGHT:   0.8  IN.
               FIN THICKNESS:  0.036  IN.             NUMBER OF PASSES:  15  (TOTAL)
                                                           HEATING SECTION:         6
     TRANSVERSE TUBE SPACING:   3.38  IN.                  BOILING SECTION:         7   (HEATING LENGTH=  0.9 FT.)
                                                           SUPERHEATING SECTION:    2   (BOILING LENGTH=  4.1 FT.)
     LONGITUDINAL TUBE SPACING:   2.92  IN.

HEAT EXCHANGER PERFORMANCE

          SECTION        GAS TEMP. IN   GAS TEMP. OUT   FLUID TEMP. IN   FLUID TEMP. OUT   REYNOLDS NUMBER (AVG.)

          HEATING           524.5          407.5            200.0            483.8              26226.9
          BOILING           743.6          524.5            483.8            486.3
          SUPERHEATING      849.0          743.6            486.3            642.5             223123.8

     STEAM PRESSURE:  600.0  PSIA  (SATURATION TEMPERATURE=  486.3  F)

     STEAM FLOW RATE:  39239.4  LBM/HR.

     GAS-SIDE PRESSURE DROP:   5.6  IN H2O

     PINCH POINT:   40.7  F

SYSTEM PERFORMANCE

     GT HORSEPOWER(REVISED):  16031.2                 ASSUMED SYSTEM CHARACTERISTICS:

     STEAM TURBINE HORSEPOWER:   5080.8                    CONDENSER PRESSURE:  4.08  IN. HG
                                                           STEAM TURBINE EFFICIENCY:  0.85
     TOTAL SYSTEM HORSEPOWER:  21112.0                     FW HEATER PRESSURE:   15.0  PSIA
                                                           LHV OF FUEL:  18400  BTU/LBM
     STEAM TURBINE SHARE OF THE LOAD:  24.1  PERCENT

     SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
          GT ONLY:  0.436     COGAS:  0.331     GT AT SYSTEM HP:  0.391

     FUEL CONSUMPTION (LBM-FUEL/HR.):
          GT ONLY:  6994.7    COGAS:  6994.6    GT AT SYSTEM HP:  8257.6

     THERMAL EFFICIENCY:
          GT ONLY:  0.317     COGAS:  0.417     GT AT SYSTEM HP:  0.354
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RUN #14

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3250.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 7 (HEATING LENGTH= 3.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	512.1	433.5	200.0	475.0	14511.6
BOILING	687.4	512.1	475.0	486.3	
SUPERHEATING	741.2	687.4	486.3	637.5	122571.0

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21557.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.3 IN H2O

PINCH POINT: 37.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8363.3

STEAM TURBINE HORSEPOWER: 2837.8

TOTAL SYSTEM HORSEPOWER: 11201.1

STEAM TURBINE SHARE OF THE LOAD: 25.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.533 COGAS: 0.396 GT AT SYSTEM HP: 0.479

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4432.6 COGAS: 4432.6 GT AT SYSTEM HP: 5368.1

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.349 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #15

06/22/75 13.01.14

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.3 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 2 (HEATING LENGTH= 4.7 FT.)
BOILING SECTION: 5 (BOILING LENGTH= 0.5 FT.)
SUPERHEATING SECTION: 2

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	511.2	456.5	200.0	456.3	5146.9
BOILING	659.5	511.2	456.3	486.3	
SUPERHEATING	687.9	659.5	486.3	640.0	44097.8

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8043.7 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

PINCH POINT: 54.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.0

STEAM TURBINE HORSEPOWER: 1039.6

TOTAL SYSTEM HORSEPOWER: 2700.5

STEAM TURBINE SHARE OF THE LOAD: 38.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.654 GT AT SYSTEM HP: 0.878

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.1 COGAS: 1766.1 GT AT SYSTEM HP: 2370.0

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.211 GT AT SYSTEM HP: 0.158

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/22/79 13.16.58

RUN #16

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.84 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 5.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	510.9	401.5	200.0	462.5	25925.0
BOILING	707.6	510.9	462.5	486.3	
SUPERHEATING	854.1	707.6	486.3	665.0	230785.6

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 39759.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.9 IN H2O

PINCH POINT: 48.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16053.3

STEAM TURBINE HORSEPOWER: 5232.3

TOTAL SYSTEM HORSEPOWER: 21285.7

STEAM TURBINE SHARE OF THE LOAD: 24.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.329 GT AT SYSTEM HP: 0.387

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6997.7 COGAS: 6997.7 GT AT SYSTEM HP: 8235.2

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.421 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #17

08/22/75 14.12.23

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGH : 1.6 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 2.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.9 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	512.9	434.0	200.0	476.3	14632.2
BOILING	644.5	512.9	476.3	486.3	
SUPERHEATING	740.4	644.5	486.3	635.0	126956.9

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21564.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.8 IN H2O

PINCH POINT: 36.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8372.4

STEAM TURBINE HORSEPOWER: 2828.4

TOTAL SYSTEM HORSEPOWER: 11200.7

STEAM TURBINE SHARE OF THE LOAD: 25.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.396 GT AT SYSTEM HP: 0.479

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4433.5 COGAS: 4433.5 GT AT SYSTEM HP: 5368.0

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.349 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/22/79 14.21.08

RUN #18

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 1.1 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 7 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 3 (HEATING LENGTH= 0.0 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	519.2	458.0	200.0	486.3	5405.2
BOILING	605.8	519.2	486.3	486.3	
SUPERHEATING	687.4	605.8	486.3	633.8	45654.2

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 7092.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.5 IN H2O

PINCH POINT: 33.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.4

STEAM TURBINE HORSEPOWER: 1028.3

TOTAL SYSTEM HORSEPOWER: 2689.7

STEAM TURBINE SHARE OF THE LOAD: 38.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.657 GT AT SYSTEM HP: 0.879

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.2 COGAS: 1766.2 GT AT SYSTEM HP: 2364.6

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.211 GT AT SYSTEM HP: 0.157

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #19

08/22/79 14.35.21

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 4.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.93 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 15 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 8 (HEATING LENGTH= 4.3 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	499.0	405.5	200.0	427.1	23808.5
BOILING	787.7	499.0	427.1	444.6	
SUPERHEATING	849.9	787.7	444.6	640.0	227181.1

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38942.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 5.3 IN H2O

PINCH POINT: 71.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16039.5

STEAM TURBINE HORSEPOWER: 4821.6

TOTAL SYSTEM HORSEPOWER: 20861.1

STEAM TURBINE SHARE OF THE LOAD: 23.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.335 GT AT SYSTEM HP: 0.396

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6995.8 COGAS: 6995.8 GT AT SYSTEM HP: 8271.2

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.412 GT AT SYSTEM HP: 0.349

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #20

08/22/79 14.56.50

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 5.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT :
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.93 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 16 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 8 (HEATING LENGTH= 3.3 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 3.2 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	476.9	403.5	200.0	434.6	14738.3
BOILING	672.2	476.9	434.6	444.6	
SUPERHEATING	741.3	672.2	444.6	637.5	143729.1

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 23807.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.8 IN H2O

PINCH POINT: 42.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8354.6

STEAM TURBINE HORSEPOWER: 2942.6

TOTAL SYSTEM HORSEPOWER: 11297.3

STEAM TURBINE SHARE OF THE LOAD: 26.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.392 GT AT SYSTEM HP: 0.478

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4431.7 COGAS: 4431.7 GT AT SYSTEM HP: 5399.8

THERMAL EFFICIENCY:
GT ONLY: 0.251 COGAS: 0.353 GT AT SYSTEM HP: 0.285

ASSUMED SYSTEM CHARACTERISTICS:
CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/22/79 15.19.43

RUN #21

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 4.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 32.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.5 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 0.7 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 1.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	472.8	410.5	200.0	442.7	5951.7
BOILING	636.5	472.8	442.7	444.6	
SUPERHEATING	687.8	636.5	444.6	635.0	56273.6

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9494.3 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.8 IN H2O

PINCH POINT: 30.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.3

STEAM TURBINE HORSEPOWER: 1171.5

TOTAL SYSTEM HORSEPOWER: 2831.8

STEAM TURBINE SHARE OF THE LOAD: 41.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.064 COGAS: 0.524 GT AT SYSTEM HP: 0.859

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.0 COGAS: 1766.0 GT AT SYSTEM HP: 2432.8

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.222 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #22

08/22/79 16.39.47

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE PACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 3.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	499.2	405.5	200.0	427.7	23652.1
BOILING	744.9	499.2	427.7	444.6	
SUPERHEATING	848.6	744.9	444.6	635.0	231167.1

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38942.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.4 IN H2O

PINCH POINT: 71.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16068.7

STEAM TURBINE HORSEPOWER: 4804.9

TOTAL SYSTEM HORSEPOWER: 20873.6

STEAM TURBINE SHARE OF THE LOAD: 23.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.335 GT AT SYSTEM HP: 0.396

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6999.8 COGAS: 6999.8 GT AT SYSTEM HP: 8270.7

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.412 GT AT SYSTEM HP: 0.349

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #23

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 7 (HEATING LENGTH= 3.2 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.9 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	474.8	401.5	200.0	433.3	14658.9
BOILING	681.3	474.8	433.3	444.6	
SUPERHEATING	739.2	681.3	444.6	623.8	139551.1

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 23545.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.2 IN H2O

PINCH POINT: 41.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8365.0

STEAM TURBINE HORSEPOWER: 2931.5

TOTAL SYSTEM HORSEPOWER: 11296.5

STEAM TURBINE SHARE OF THE LOAD: 26.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.392 GT AT SYSTEM HP: 0.478

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4432.8 COGAS: 4432.7 GT AT SYSTEM HP: 5399.5

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.352 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #24

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 1.2 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 0.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	473.8	412.6	200.0	440.2	5841.8
BOILING	658.9	473.8	440.2	444.6	
SUPERHEATING	688.5	658.9	444.6	632.5	53585.1

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9425.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.7 IN H2O

PINCH POINT: 33.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.9

STEAM TURBINE HORSEPOWER: 1161.0

TOTAL SYSTEM HORSEPOWER: 2821.9

STEAM TURBINE SHARE OF THE LOAD: 41.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.626 GT AT SYSTEM HP: 0.860

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.1 COGAS: 1766.1 GT AT SYSTEM HP: 2428.1

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.221 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #25

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8. SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 2.0 FT.)
SUPERHEATING SECTION: 1 (BOILING LENGTH= 0.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	504.0	409.0	200.0	432.1	23810.6
BOILING	799.6	504.0	432.1	444.6	
SUPERHEATING	848.4	799.6	444.6	624.3	213343.7

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38643.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.5 IN H2O

PINCH POINT: 71.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16098.5

STEAM TURBINE HORSEPOWER: 4732.7

TOTAL SYSTEM HORSEPOWER: 20831.3

STEAM TURBINE SHARE OF THE LOAD: 22.7 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.336 GT AT SYSTEM HP: 0.397

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7003.9 COGAS: 7003.9 GT AT SYSTEM HP: 8271.2

THERMAL EFFICIENCY:
GT ONLY: 0.313 COGAS: 0.411 GT AT SYSTEM HP: 0.348

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #26

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 1.6 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 2.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	475.1	401.5	200.0	434.0	14789.1
BOILING	643.7	475.1	434.0	444.6	
SUPERHEATING	740.8	643.7	444.6	635.0	143151.9

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 23945.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.7 IN H2O

PINCH POINT: 41.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8373.8

STEAM TURBINE HORSEPOWER: 2954.5

TOTAL SYSTEM HORSEPOWER: 11328.3

STEAM TURBINE SHARE OF THE LOAD: 26.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.391 GT AT SYSTEM HP: 0.478

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4433.6 COGAS: 4433.6 GT AT SYSTEM HP: 5410.0

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.353 GT AT SYSTEM HP: 0.290

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #27

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 1.3 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 8 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 4 (HEATING LENGTH= 3.0 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	468.2	409.6	200.0	428.3	5831.0
BOILING	611.7	468.2	428.3	444.6	
SUPERHEATING	688.2	611.7	444.6	637.5	55609.7

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9526.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

PINCH POINT: 39.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.2

STEAM TURBINE HORSEPOWER: 1177.4

TOTAL SYSTEM HORSEPOWER: 2838.5

STEAM TURBINE SHARE OF THE LOAD: 41.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.522 GT AT SYSTEM HP: 0.858

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.2 COGAS: 1766.2 GT AT SYSTEM HP: 2436.0

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.222 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/15/79 15.09.46

RUN #28

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 5.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 40.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 18 (TOTAL)
HEATING SECTION: 8
BOILING SECTION: 8 (HEATING LENGTH= 1.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	549.0	419.0	200.0	516.4	22078.2
BOILING	764.6	549.0	516.4	518.3	
SUPERHEATING	849.2	764.6	518.3	643.8	170747.6

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 38770.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.3 IN H2O

PINCH POINT: 32.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16072.2

STEAM TURBINE HORSEPOWER: 5132.8

TOTAL SYSTEM HORSEPOWER: 21205.0

STEAM TURBINE SHARE OF THE LOAD: 24.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.330 GT AT SYSTEM HP: 0.389

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7000.3 COGAS: 7000.3 GT AT SYSTEM HP: 8246.9

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.419 GT AT SYSTEM HP: 0.356

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/15/79 15.45.59

RUN #29

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 4.6 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 40.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 14 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 7 (HEATING LENGTH= 1.6 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.0 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	546.3	462.9	200.0	515.2	11488.2
BOILING	706.9	546.3	515.2	518.3	
SUPERHEATING	740.5	706.9	518.3	641.3	87717.6

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 20212.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.4 IN H2O

PINCH POINT: 31.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8378.9

STEAM TURBINE HORSEPOWER: 2670.5

TOTAL SYSTEM HORSEPOWER: 11049.4

STEAM TURBINE SHARE OF THE LOAD: 24.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.401 GT AT SYSTEM HP: 0.481

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4434.2 COGAS: 4434.2 GT AT SYSTEM HP: 5318.0

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.345 GT AT SYSTEM HP: 0.287

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #30

08/15/75 15.54.15

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 3.3 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 40.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 4 (HEATING LENGTH= 2.4 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 3.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	545.1	485.5	200.0	510.2	4033.4
BOILING	633.9	545.1	510.2	516.3	
SUPERHEATING	688.6	633.9	518.3	647.5	31670.3

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7149.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.5 IN H2O

PINCH POINT: 35.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.6

STEAM TURBINE HORSEPOWER: 949.3

TOTAL SYSTEM HORSEPOWER: 2610.9

STEAM TURBINE SHARE OF THE LOAD: 36.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.677 GT AT SYSTEM HP: 0.891

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.3 COGAS: 1766.3 GT AT SYSTEM HP: 2325.5

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.204 GT AT SYSTEM HP: 0.155

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/15/75 20.50.10

RUN #31

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 3.7 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 15 (TOTAL)
HEATING SECTION: 6
BOILING SECTION: 7 (HEATING LENGTH= 5.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	540.9	415.0	200.0	504.5	21620.1
BOILING	730.7	540.9	504.5	518.3	
SUPERHEATING	849.8	730.7	518.3	647.5	172417.9

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 39123.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.7 IN H2O

PINCH POINT: 36.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16092.0

STEAM TURBINE HORSEPOWER: 5154.9

TOTAL SYSTEM HORSEPOWER: 21287.0

STEAM TURBINE SHARE OF THE LOAD: 24.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.329 GT AT SYSTEM HP: 0.387

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7003.0 COGAS: 7003.0 GT AT SYSTEM HP: 8235.5

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.420 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #32

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 15.2 FT.
- HEIGHT: 2.7 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: [illegible] IN.
- INSIDE TUBE DIAMETER: 1.4 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 7.92 FINS/IN.
  - FIN HEIGHT: 0.8 IN.
  - FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 11 (TOTAL)
- HEATING SECTION: 4
- BOILING SECTION: 5 (HEATING LENGTH= 0.4 FT.)
- SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	548.8	465.1	200.0	518.3	11317.2
BOILING	675.4	548.8	518.3	518.3	
SUPERHEATING	740.6	675.4	518.3	637.5	87322.8

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 20052.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.9 IN H2O

PINCH POINT: 30.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8387.7

STEAM TURBINE HORSEPOWER: 2641.5

TOTAL SYSTEM HORSEPOWER: 11029.2

STEAM TURBINE SHARE OF THE LOAD: 23.9 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.527 COGAS: 0.402 GT AT SYSTEM HP: 0.482

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4435.1 COGAS: 4435.1 GT AT SYSTEM HP: 5311.3

THERMAL EFFICIENCY:
GT ONLY: 0.262 COGAS: 0.344 GT AT SYSTEM HP: 0.287

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

RUN #33

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 8 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 4 (HEATING LENGTH= 4.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.6 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	540.4	484.0	200.0	492.7	3901.9
BOILING	652.7	540.4	492.7	518.3	
SUPERHEATING	688.7	652.7	518.3	647.5	30667.8

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7201.1 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.4 IN H2O

PINCH POINT: 47.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.9

STEAM TURBINE HORSEPOWER: 956.2

TOTAL SYSTEM HORSEPOWER: 2618.1

STEAM TURBINE SHARE OF THE LOAD: 36.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.675 GT AT SYSTEM HP: 0.890

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.3 COGAS: 1766.3 GT AT SYSTEM HP: 2329.1

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.205 GT AT SYSTEM HP: 0.155

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #34

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 6 (HEATING LENGTH= 1.9 FT.)
SUPERHEATING SECTION: 1 (BOILING LENGTH= 0.7 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	544.6	414.2	200.0	513.9	22250.0
BOILING	797.0	544.6	513.9	518.3	
SUPERHEATING	851.1	797.0	518.3	649.3	163175.6

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 39189.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.3 IN H2O

PINCH POINT: 30.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16107.1

STEAM TURBINE HORSEPOWER: 5211.1

TOTAL SYSTEM HORSEPOWER: 21318.2

STEAM TURBINE SHARE OF THE LOAD: 24.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.329 GT AT SYSTEM HP: 0.386

* FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7005.1 COGAS: 7005.1 GT AT SYSTEM HP: 8230.2

THERMAL EFFICIENCY:
GT ONLY: 0.313 COGAS: 0.421 GT AT SYSTEM HP: 0.358

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #35

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 4 (HEATING LENGTH= 1.6 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	543.7	459.9	200.0	513.3	11569.7
BOILING	643.5	543.7	513.3	518.3	
SUPERHEATING	741.8	643.5	518.3	645.0	91410.0

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 20426.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.7 IN H2O

PINCH POINT: 30.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8391.1

STEAM TURBINE HORSEPOWER: 2706.8

TOTAL SYSTEM HORSEPOWER: 11098.0

STEAM TURBINE SHARE OF THE LOAD: 24.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.400 GT AT SYSTEM HP: 0.481

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4435.4 COGAS: 4435.4 GT AT SYSTEM HP: 5334.1

THERMAL EFFICIENCY:
GT ONLY: 0.262 COGAS: 0.346 GT AT SYSTEM HP: 0.288

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #36

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.0 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 6 (TOTAL)
HEATING SECTION: 1
BOILING SECTION: 3 (HEATING LENGTH= 5.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	532.5	485.5	200.0	448.3	3656.6
BOILING	616.2	532.5	448.3	518.3	
SUPERHEATING	689.0	616.2	518.3	646.3	31476.1

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7149.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.3 IN H2O

PINCH POINT: 84.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1662.2

STEAM TURBINE HORSEPOWER: 948.3

TOTAL SYSTEM HORSEPOWER: 2610.5

STEAM TURBINE SHARE OF THE LOAD: 36.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.677 GT AT SYSTEM HP: 0.891

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.4 COGAS: 1766.4 GT AT SYSTEM HP: 2325.3

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.204 GT AT SYSTEM HP: 0.155

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/15/79 13.40.09

RUN #37

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 5.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.93 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 40.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 17 (TOTAL)
HEATING SECTION: 7
BOILING SECTION: 8 (HEATING LENGTH= 1.3 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.6 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	522.5	405.0	200.0	483.8	21261.9
BOILING	769.5	522.5	483.8	486.3	
SUPERHEATING	848.8	769.5	486.3	640.0	178832.9

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 39455.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.0 IN H2O

PINCH POINT: 38.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16081.9

STEAM TURBINE HORSEPOWER: 5099.4

TOTAL SYSTEM HORSEPOWER: 21181.4

STEAM TURBINE SHARE OF THE LOAD: 24.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.331 GT AT SYSTEM HP: 0.389

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7001.6 COGAS: 7001.6 GT AT SYSTEM HP: 8249.9

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.418 GT AT SYSTEM HP: 0.355

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #38

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 4.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 40.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 15 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 8 (HEATING LENGTH= 3.2 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 0.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	511.5	431.0	200.0	478.8	11871.6
BOILING	709.7	511.5	478.8	486.3	
SUPERHEATING	741.7	709.7	486.3	637.5	98751.3

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 22173.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.4 IN H2O

PINCH POINT: 32.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8378.6

STEAM TURBINE HORSEPOWER: 2860.6

TOTAL SYSTEM HORSEPOWER: 11239.3

STEAM TURBINE SHARE OF THE LOAD: 25.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.395 GT AT SYSTEM HP: 0.475

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4434.1 COGAS: 4434.1 GT AT SYSTEM HP: 5380.7

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.351 GT AT SYSTEM HP: 0.285

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #39

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 3.6 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 40.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 11 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 3.4 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.0 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	511.0	450.9	200.0	473.8	4370.5
BOILING	622.1	511.0	473.8	486.3	
SUPERHEATING	687.9	622.1	486.3	637.5	37903.1

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8234.7 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.5 IN H2O

PINCH POINT: 37.3 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.5

STEAM TURBINE HORSEPOWER: 1062.4

TOTAL SYSTEM HORSEPOWER: 2723.9

STEAM TURBINE SHARE OF THE LOAD: 39.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.648 GT AT SYSTEM HP: 0.874

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.2 COGAS: 1766.2 GT AT SYSTEM HP: 2381.3

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.213 GT AT SYSTEM HP: 0.158

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.00 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #40

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 3.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 14 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 7 (HEATING LENGTH= 5.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	513.4	402.3	200.0	467.5	20576.3
BOILING	737.5	513.4	467.5	486.3	
SUPERHEATING	850.6	737.5	486.3	650.0	179758.6

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 39693.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.5 IN H2O

PINCH POINT: 45.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16101.5

STEAM TURBINE HORSEPOWER: 5167.7

TOTAL SYSTEM HORSEPOWER: 21269.2

STEAM TURBINE SHARE OF THE LOAD: 24.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.329 GT AT SYSTEM HP: 0.387

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7004.3 COGAS: 7004.3 GT AT SYSTEM HP: 8237.9

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.420 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:
CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #41

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 0.9 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	516.0	435.0	200.0	484.4	11664.0
BOILING	683.2	516.0	484.4	486.3	
SUPERHEATING	741.7	683.2	486.3	641.3	97271.8

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21894.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.0 IN H2O

PINCH POINT: 31.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8385.5

STEAM TURBINE HORSEPOWER: 2832.3

TOTAL SYSTEM HORSEPOWER: 11217.8

STEAM TURBINE SHARE OF THE LOAD: 25.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.527 COGAS: 0.395 GT AT SYSTEM HP: 0.479

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4434.8 COGAS: 4434.8 GT AT SYSTEM HP: 5373.6

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.350 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #42

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 5 (HEATING LENGTH= 5.2 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 0.9 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	505.6	449.4	200.0	455.0	4212.0
BOILING	653.8	505.6	455.0	486.3	
SUPERHEATING	687.9	653.8	486.3	641.3	36232.5

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8285.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.4 IN H2O

PINCH POINT: 50.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.7

STEAM TURBINE HORSEPOWER: 1071.9

TOTAL SYSTEM HORSEPOWER: 2733.6

STEAM TURBINE SHARE OF THE LOAD: 39.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.646 GT AT SYSTEM HP: 0.873

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.3 COGAS: 1766.3 GT AT SYSTEM HP: 2386.0

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.214 GT AT SYSTEM HP: 0.158

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #43

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.8 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 11 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 3.6 FT.)
SUPERHEATING SECTION: 1 (BOILING LENGTH= C.6 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	514.5	400.8	200.0	472.5	21083.2
BOILING	792.6	514.5	472.5	486.3	
SUPERHEATING	849.7	792.6	486.3	642.1	169625.8

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 35818.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.0 IN H2O

PINCH POINT: 42.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16117.5

STEAM TURBINE HORSEPOWER: 5154.2

TOTAL SYSTEM HORSEPOWER: 21271.7

STEAM TURBINE SHARE OF THE LOAD: 24.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.329 GT AT SYSTEM HP: 0.387

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7006.5 COGAS: 7006.5 GT AT SYSTEM HP: 8237.5

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.420 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #44

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 4 (HEATING LENGTH= 0.2 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.2 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	517.8	436.5	200.0	486.3	11788.4
BOILING	635.8	517.8	486.3	486.3	
SUPERHEATING	740.9	635.8	486.3	638.8	100947.2

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21789.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.6 IN H2O

PINCH POINT: 31.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8391.7

STEAM TURBINE HORSEPOWER: 2813.6

TOTAL SYSTEM HORSEPOWER: 11205.3

STEAM TURBINE SHARE OF THE LOAD: 25.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.396 GT AT SYSTEM HP: 0.479

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4435.5 COGAS: 4435.5 GT AT SYSTEM HP: 5369.5

THERMAL EFFICIENCY:
GT ONLY: 0.262 COGAS: 0.349 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #45

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.1 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 7 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 3 (HEATING LENGTH= 0.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	514.9	452.4	200.0	485.0	4418.5
BOILING	601.8	514.9	485.0	486.3	
SUPERHEATING	687.7	601.8	486.3	636.3	37418.6

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8183.6 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.3 IN H2O

PINCH POINT: 29.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1662.0

STEAM TURBINE HORSEPOWER: 1054.8

TOTAL SYSTEM HORSEPOWER: 2716.8

STEAM TURBINE SHARE OF THE LOAD: 38.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.650 GT AT SYSTEM HP: 0.875

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.3 COGAS: 1766.3 GT AT SYSTEM HP: 2377.5

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.213 GT AT SYSTEM HP: 0.158

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

03/17/79 10.20.19

RUN #46

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

```
BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)
```

HEAT EXCHANGER GEOMETRY

```
OVERALL DIMENSIONS:                         NUMBER OF ROWS PER PASS:    1.
     LENGTH:  12.0  FT.                     NUMBER OF TUBES PER ROW:   40.
     WIDTH:   15.0  FT.                     TUBE LENGTH  12.  FT.
     HEIGHT:   4.6  FT.                     OUTSIDE AREA/PASS:   4081.2  SQ.FT.
HEAT TRANSFER SURFACE                       INSIDE AREA/PASS:   234.4  SQ. FT.
     OUTSIDE TUBE DIAMETER:   2.0  IN.      FRONTAL AREA:  179.5  SQ. FT.
     INSIDE TUBE DIAMETER:   1.9  IN.       NUMBER OF PASSES:  14  (TOTAL)
     TUBE/FIN ARRANGEMENT:                       HEATING SECTION:      5
          FIN TYPE:  SEGMENTED                   BOILING SECTION:      7   (HEATING LENGTH=  2.8 FT.)
          FIN SPACING:   5.94  FINS/IN.          SUPERHEATING SECTION:  2   (BOILING LENGTH=  2.2 FT.)
          FIN HEIGHT:  1.0  IN.
          FIN THICKNESS:  0.048  IN.
TRANSVERSE TUBE SPACING:   4.50  IN.
LONGITUDINAL TUBE SPACING:   3.90  IN.
```

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	497.8	400.5	200.0	433.3	19452.2
BOILING	766.2	497.8	433.3	444.6	
SUPERHEATING	847.9	766.2	444.6	632.5	186080.6

```
STEAM PRESSURE:  400.0  PSIA  (SATURATION TEMPERATURE=  444.6  F)
STEAM FLOW RATE:  39368.9  LBM/HR.
GAS-SIDE PRESSURE DROP:   3.3  IN H2O
PINCH POINT:   64.4  F
```

SYSTEM PERFORMANCE

```
GT HORSEPOWER(REVISED):  16106.7              ASSUMED SYSTEM CHARACTERISTICS:
STEAM TURBINE HORSEPOWER:   4849.2                 CONDENSER PRESSURE:   4.08  IN. HG
TOTAL SYSTEM HORSEPOWER:  20955.9                  STEAM TURBINE EFFICIENCY:  0.85
STEAM TURBINE SHARE OF THE LOAD:  23.1  PERCENT    FW HEATER PRESSURE:   15.0  PSIA
                                                   LHV OF FUEL:  18400  BTU/LBM
SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
     GT ONLY:  0.435    COGAS:  0.334    GT AT SYSTEM HP:  0.395
FUEL CONSUMPTION (LBM-FUEL/HR.):
     GT ONLY:  7005.0   COGAS:  7005.0   GT AT SYSTEM HP:  8268.1
THERMAL EFFICIENCY:
     GT ONLY:  0.318    COGAS:  0.414    GT AT SYSTEM HP:  0.350
```

RUN #47

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

```
BRAKE HORSEPOWER:   8526.0,  APPROXIMATE CORRESPONDING SHIP SPEED:  16.0  KTS
EXHAUST GAS TEMPERATURE:   742.0  F
EXHAUST GAS FLOW RATE:  328641.0  LBM/HR  ( 91.3   LBM/SEC)
```

HEAT EXCHANGER GEOMETRY

```
OVERALL DIMENSIONS:                              NUMBER OF ROWS PER PASS:    1.
     LENGTH:   12.0  FT.
     WIDTH:    15.0  FT.                         NUMBER OF TUBES PER  ROW:   40.
     HEIGHT:    4.5  FT.
                                                 TUBE LENGTH  12.  FT.
HEAT TRANSFER SURFACE
     OUTSIDE TUBE DIAMETER:   2.0   IN.          OUTSIDE AREA/PASS:   4081.2  SQ.FT.
     INSIDE TUBE DIAMETER:   1.9   IN.
     TUBE/FIN ARRANGEMENT:                       INSIDE AREA/PASS:   234.4  SQ. FT.
         FIN TYPE:   SEGMENTED
         FIN SPACING:   5.94   FINS/IN.          FRONTAL AREA:  179.5   SQ. FT.
         FIN HEIGHT:  1.0  IN.
         FIN THICKNESS:  0.048  IN.              NUMBER OF PASSES:  15   (TOTAL)
                                                      HEATING SECTION:        5
TRANSVERSE TUBE SPACING:   4.50  IN.                  BOILING SECTION:        7   (HEATING LENGTH=  1.6 FT.)
                                                      SUPERHEATING SECTION:   3   (BOILING LENGTH=  4.3 FT.)
LONGITUDINAL TUBE SPACING:   3.90  IN.
```

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	477.1	401.5	200.0	440.2	11965.7
BOILING	657.4	477.1	440.2	444.6	
SUPERHEATING	740.9	657.4	444.6	636.3	116558.0

```
STEAM PRESSURE:  400.0  PSIA  (SATURATION TEMPERATURE=  444.6  F)

STEAM FLOW RATE:  23945.2  LBM/HR.

GAS-SIDE PRESSURE DROP:   2.4   IN H2O

PINCH POINT:   36.9  F
```

SYSTEM PERFORMANCE

```
GT HORSEPOWER(REVISED):   8379.3                 ASSUMED SYSTEM CHARACTERISTICS:

STEAM TURBINE HORSEPOWER:   2957.1                    CONDENSER PRESSURE:  4.08  IN. HG
                                                      STEAM TURBINE EFFICIENCY:  0.85
TOTAL SYSTEM HORSEPOWER:  11336.4                     FW HEATER PRESSURE:   15.0  PSIA
                                                      LHV OF FUEL:  18400  BTU/LBM
STEAM TURBINE SHARE OF THE LOAD:   26.1  PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
     GT ONLY:  0.527     COGAS:  0.391     GT AT SYSTEM HP:  0.477

FUEL CONSUMPTION (LBM-FUEL/HR.):
     GT ONLY:  4434.2    COGAS:  4434.2    GT AT SYSTEM HP:  5412.6

THERMAL EFFICIENCY:
     GT ONLY:  0.261     COGAS:  0.354     GT AT SYSTEM HP:  0.290
```

RUN #48

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 3.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 2.0 IN.
INSIDE TUBE DIAMETER: 1.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 5.94 FINS/IN.
FIN HEIGHT: 1.0 IN.
FIN THICKNESS: 0.048 IN.

TRANSVERSE TUBE SPACING: 4.50 IN.

LONGITUDINAL TUBE SPACING: 3.90 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 40.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.5 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3 (HEATING LENGTH= 4.7 FT.)
BOILING SECTION: 6
SUPERHEATING SECTION: 3 (BOILING LENGTH= 0.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	467.2	409.6	200.0	424.6	4630.8
BOILING	651.4	467.2	424.6	444.6	
SUPERHEATING	688.5	651.4	444.6	646.3	44609.7

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9524.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.5 IN H2O

PINCH POINT: 42.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.4

STEAM TURBINE HORSEPOWER: 1184.4

TOTAL SYSTEM HORSEPOWER: 2845.7

STEAM TURBINE SHARE OF THE LOAD: 41.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.621 GT AT SYSTEM HP: 0.857

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.2 COGAS: 1766.2 GT AT SYSTEM HP: 2439.3

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.223 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/16/79 15.46.35

RUN #49

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.7 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 11 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 5 (HEATING LENGTH= 1.0 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	504.4	405.5	200.0	439.6	19194.8
BOILING	729.8	504.4	439.6	444.6	
SUPERHEATING	849.2	729.8	444.6	640.0	184657.6

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38942.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.7 IN H2O

PINCH POINT: 64.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16127.1

STEAM TURBINE HORSEPOWER: 4821.6

TOTAL SYSTEM HORSEPOWER: 20948.7

STEAM TURBINE SHARE OF THE LOAD: 23.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.335 GT AT SYSTEM HP: 0.395

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7007.8 COGAS: 7007.8 GT AT SYSTEM HP: 8268.1

THERMAL EFFICIENCY:
GT ONLY: 0.313 COGAS: 0.413 GT AT SYSTEM HP: 0.350

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #50

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 1.1 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	477.3	401.5	200.0	440.8	11817.9
BOILING	687.0	477.3	440.8	444.6	
SUPERHEATING	741.8	687.0	444.6	640.0	109744.9

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 23945.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.9 IN H2O

PINCH POINT: 36.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8386.5

STEAM TURBINE HORSEPOWER: 2964.8

TOTAL SYSTEM HORSEPOWER: 11351.3

STEAM TURBINE SHARE OF THE LOAD: 26.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.391 GT AT SYSTEM HP: 0.477

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4434.9 COGAS: 4434.9 GT AT SYSTEM HP: 5417.5

THERMAL EFFICIENCY:
GT ONLY: 0.262 COGAS: 0.354 GT AT SYSTEM HP: 0.290

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #51

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 4 (HEATING LENGTH= 0.7 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	472.0	409.6	200.0	442.1	4712.4
BOILING	568.2	472.0	442.1	444.6	
SUPERHEATING	588.4	588.2	444.6	642.5	45957.4

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9524.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.4 IN H2O

PINCH POINT: 29.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.7

STEAM TURBINE HORSEPOWER: 1181.3

TOTAL SYSTEM HORSEPOWER: 2843.0

STEAM TURBINE SHARE OF THE LOAD: 41.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.621 GT AT SYSTEM HP: 0.858

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.3 COGAS: 1766.3 GT AT SYSTEM HP: 2438.0

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.223 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #52

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.3 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 8 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 4 (HEATING LENGTH= 5.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	488.5	410.2	200.0	394.6	17739.5
BOILING	681.7	488.5	394.6	444.6	
SUPERHEATING	851.8	681.7	444.6	657.5	190071.5

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38544.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.2 IN H2O

PINCH POINT: 93.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16143.9

STEAM TURBINE HORSEPOWER: 4830.4

TOTAL SYSTEM HORSEPOWER: 20974.3

STEAM TURBINE SHARE OF THE LOAD: 23.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.434 COGAS: 0.334 GT AT SYSTEM HP: 0.394

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7010.1 COGAS: 7010.1 GT AT SYSTEM HP: 8267.0

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.414 GT AT SYSTEM HP: 0.351

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #53

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3 (HEATING LENGTH= 0.3 FT.)
BOILING SECTION: 4 (BOILING LENGTH= 4.7 FT.)
SUPERHEATING SECTION: 2

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	481.5	405.1	200.0	444.6	11921.6
BOILING	621.7	481.5	444.6	444.6	
SUPERHEATING	739.6	621.7	444.6	630.0	115150.3

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 23698.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.6 IN H2O

PINCH POINT: 36.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8392.6

STEAM TURBINE HORSEPOWER: 2913.9

TOTAL SYSTEM HORSEPOWER: 11306.5

STEAM TURBINE SHARE OF THE LOAD: 25.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.392 GT AT SYSTEM HP: 0.478

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4435.6 COGAS: 4435.6 GT AT SYSTEM HP: 5402.8

THERMAL EFFICIENCY:
GT ONLY: 0.262 COGAS: 0.352 GT AT SYSTEM HP: 0.285

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #54

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.1 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 7 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 3 (HEATING LENGTH= 0.0 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.6 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	480.8	420.0	200.0	444.6	4615.9
BOILING	594.7	480.8	444.6	444.6	
SUPERHEATING	687.9	594.7	444.6	637.5	43360.5

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9175.6 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.3 IN H2O

PINCH POINT: 36.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1662.0

STEAM TURBINE HORSEPOWER: 1134.1

TOTAL SYSTEM HORSEPOWER: 2796.2

STEAM TURBINE SHARE OF THE LOAD: 40.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.632 GT AT SYSTEM HP: 0.864

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.4 COGAS: 1766.4 GT AT SYSTEM HP: 2416.0

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.219 GT AT SYSTEM HP: 0.160

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #4(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 3.7 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 0.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	532.6	470.0	200.0	507.0	5281.1
BOILING	662.0	532.6	507.0	518.3	
SUPERHEATING	688.3	662.0	518.3	668.8	40471.1

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7577.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.9 IN H2O

PINCH POINT: 25.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.2

STEAM TURBINE HORSEPOWER: 1022.8

TOTAL SYSTEM HORSEPOWER: 2683.0

STEAM TURBINE SHARE OF THE LOAD: 38.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.064 COGAS: 0.658 GT AT SYSTEM HP: 0.880

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1765.9 COGAS: 1765.9 GT AT SYSTEM HP: 2361.4

THERMAL EFFICIENCY:
GT ONLY: 0.133 COGAS: 0.210 GT AT SYSTEM HP: 0.157

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #5

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.33 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3250.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 2.1 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	547.5	465.9	200.0	511.4	14023.8
BOILING	682.5	547.5	511.4	518.3	
SUPERHEATING	740.6	682.5	518.3	635.0	109056.4

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 19998.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.1 IN H2O

PINCH POINT: 30.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8366.4

STEAM TURBINE HORSEPOWER: 2629.1

TOTAL SYSTEM HORSEPOWER: 10995.6

STEAM TURBINE SHARE OF THE LOAD: 23.9 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.403 GT AT SYSTEM HP: 0.482

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4432.5 COGAS: 4432.5 GT AT SYSTEM HP: 5300.1

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.343 GT AT SYSTEM HP: 0.287

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #6(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.52 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 6 (HEATING LENGTH= 0.3 FT.)
SUPERHEATING SECTION: 1 (BOILING LENGTH= 0.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	572.0	451.5	200.0	517.0	25426.2
BOILING	814.7	572.0	517.0	518.3	
SUPERHEATING	847.7	814.7	518.3	630.2	187516.3

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 35912.3 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.5 IN H2O

PINCH POINT: 55.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16066.0

STEAM TURBINE HORSEPOWER: 4703.0

TOTAL SYSTEM HORSEPOWER: 20769.1

STEAM TURBINE SHARE OF THE LOAD: 22.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.337 GT AT SYSTEM HP: 0.398

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6999.4 COGAS: 6999.4 GT AT SYSTEM HP: 8271.3

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.410 GT AT SYSTEM HP: 0.347

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #14

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.3 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 7 (HEATING LENGTH= 3.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	512.1	433.5	200.0	475.0	14511.6
BOILING	587.4	512.1	475.0	486.3	
SUPERHEATING	741.2	687.4	486.3	637.5	122571.0

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21557.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.3 IN H2O

PINCH POINT: 37.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8363.3

STEAM TURBINE HORSEPOWER: 2837.8

TOTAL SYSTEM HORSEPOWER: 11201.1

STEAM TURBINE SHARE OF THE LOAD: 25.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.396 GT AT SYSTEM HP: 0.475

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4432.6 COGAS: 4432.6 GT AT SYSTEM HP: 5368.1

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.349 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #13(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 12.1 FT.
- HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: 1.5 IN.
- INSIDE TUBE DIAMETER: 1.4 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 7.92 FINS/IN.
  - FIN HEIGHT: 0.8 IN.
  - FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
- HEATING SECTION: 5
- BOILING SECTION: 6 (HEATING LENGTH= 1.5 FT.)
- SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	534.1	422.3	200.0	480.6	25259.9
BOILING	742.8	534.1	480.6	486.3	
SUPERHEATING	848.4	742.8	486.3	638.8	216614.1

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 37562.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.9 IN H2O

PINCH POINT: 53.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16053.9

STEAM TURBINE HORSEPOWER: 4902.1

TOTAL SYSTEM HORSEPOWER: 20955.9

STEAM TURBINE SHARE OF THE LOAD: 23.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.334 GT AT SYSTEM HP: 0.395

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6997.8 COGAS: 6997.8 GT AT SYSTEM HP: 8268.2

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.414 GT AT SYSTEM HP: 0.350

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

08/27/79 15.48.33

RUN #15(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 3 (HEATING LENGTH= 4.8 FT.)
BOILING SECTION: 6 (BOILING LENGTH= 4.3 FT.)
SUPERHEATING SECTION: 4

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	498.9	436.5	200.0	471.3	5643.0
BOILING	611.5	498.9	471.3	486.3	
SUPERHEATING	688.6	611.5	486.3	667.5	49203.8

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8612.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.9 IN H2O

PINCH POINT: 21.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.1

STEAM TURBINE HORSEPOWER: 1135.5

TOTAL SYSTEM HORSEPOWER: 2795.6

STEAM TURBINE SHARE OF THE LOAD: 40.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.064 COGAS: 0.632 GT AT SYSTEM HP: 0.864

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1765.9 COGAS: 1765.9 GT AT SYSTEM HP: 2415.7

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.219 GT AT SYSTEM HP: 0.160

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #18(o)

08/25/79 13.13.56

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 3.7 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.0 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	493.7	427.0	200.0	478.8	5969.5
BOILING	605.4	493.7	478.8	486.3	
SUPERHEATING	688.5	605.4	486.3	667.5	50891.9

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8931.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.9 IN H2O

PINCH POINT: 15.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.1

STEAM TURBINE HORSEPOWER: 1177.6

TOTAL SYSTEM HORSEPOWER: 2837.7

STEAM TURBINE SHARE OF THE LOAD: 41.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.064 COGAS: 0.622 GT AT SYSTEM HP: 0.858

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1765.9 COGAS: 1765.9 GT AT SYSTEM HP: 2435.6

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.222 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #17(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 3526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.00 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 187.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 0.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	506.3	421.5	200.0	435.0	15413.7
BOILING	656.1	506.3	485.0	486.3	
SUPERHEATING	742.5	656.1	486.3	647.5	125980.6

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 22838.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.3 IN H2O

PINCH POINT: 21.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8363.5

STEAM TURBINE HORSEPOWER: 2967.9

TOTAL SYSTEM HORSEPOWER: 11331.4

STEAM TURBINE SHARE OF THE LOAD: 26.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.391 GT AT SYSTEM HP: 0.478

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4432.6 COGAS: 4432.6 GT AT SYSTEM HP: 5411.0

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.354 GT AT SYSTEM HP: 0.290

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.09 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/22/79 13.16.58

RUN #16

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.0 FT.
HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 64.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3264.9 SQ.FT.

INSIDE AREA/PASS: 167.5 SQ. FT.

FRONTAL AREA: 143.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 5.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	510.9	401.5	200.0	462.5	25925.0
BOILING	707.6	510.9	462.5	486.3	
SUPERHEATING	854.1	707.6	486.3	665.0	230785.6

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 39759.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.9 IN H2O

PINCH POINT: 48.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16053.3

STEAM TURBINE HORSEPOWER: 5232.3

TOTAL SYSTEM HORSEPOWER: 21285.7

STEAM TURBINE SHARE OF THE LOAD: 24.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.329 GT AT SYSTEM HP: 0.387

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6997.7 COGAS: 6997.7 GT AT SYSTEM HP: 8235.2

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.421 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #24(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 1.9 FT.)
SUPERHEATING SECTION: 4 (BOILING LENGTH= 1.9 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	470.2	410.0	200.0	437.7	5779.9
BOILING	630.3	470.2	437.7	444.6	
SUPERHEATING	688.9	630.3	444.6	672.5	54546.6

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9377.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.8 IN H2O

PINCH POINT: 32.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.4

STEAM TURBINE HORSEPOWER: 1187.4

TOTAL SYSTEM HORSEPOWER: 2847.8

STEAM TURBINE SHARE OF THE LOAD: 41.7 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.064 COGAS: 0.620 GT AT SYSTEM HP: 0.857

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.0 COGAS: 1766.0 GT AT SYSTEM HP: 2440.3

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.223 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/25/79 13.57.41

RUN #23(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 1.1 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	499.9	431.5	200.0	438.3	13513.8
BOILING	699.7	499.9	438.3	444.6	
SUPERHEATING	741.2	689.7	444.6	633.8	126450.5

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 21974.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.5 IN H2O

PINCH POINT: 61.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8376.7

STEAM TURBINE HORSEPOWER: 2696.7

TOTAL SYSTEM HORSEPOWER: 11073.4

STEAM TURBINE SHARE OF THE LOAD: 24.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.400 GT AT SYSTEM HP: 0.481

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4433.5 COGAS: 4433.9 GT AT SYSTEM HP: 5326.0

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.345 GT AT SYSTEM HP: 0.288

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #22(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 3.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.0 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	515.6	431.0	200.0	419.0	21962.6
BOILING	738.2	515.6	419.0	444.6	
SUPERHEATING	847.5	738.2	444.6	631.3	219577.9

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 36760.7 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.8 IN H2O

PINCH POINT: 96.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16090.9

STEAM TURBINE HORSEPOWER: 4524.0

TOTAL SYSTEM HORSEPOWER: 20614.9

STEAM TURBINE SHARE OF THE LOAD: 21.9 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.340 GT AT SYSTEM HP: 0.401

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7002.8 COGAS: 7002.8 GT AT SYSTEM HP: 8266.2

THERMAL EFFICIENCY:
GT ONLY: 0.319 COGAS: 0.407 GT AT SYSTEM HP: 0.345

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #24

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 10 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 1.2 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 0.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	473.8	412.6	200.0	440.2	5841.8
BOILING	658.9	473.8	440.2	444.6	
SUPERHEATING	688.5	658.9	444.6	632.5	53585.1

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9425.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.7 IN H2O

PINCH POINT: 33.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.9

STEAM TURBINE HORSEPOWER: 1161.0

TOTAL SYSTEM HORSEPOWER: 2821.9

STEAM TURBINE SHARE OF THE LOAD: 41.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.626 GT AT SYSTEM HP: 0.860

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.1 COGAS: 1766.1 GT AT SYSTEM HP: 2428.1

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.221 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/25/79 13.47.43

RUN #23(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 0.0 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.0 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	486.3	411.5	200.0	444.6	14510.6
BOILING	694.1	486.3	444.6	444.6	
SUPERHEATING	741.5	694.1	444.6	637.5	133818.8

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 23255.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.0 IN H2O

PINCH POINT: 41.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8368.8

STEAM TURBINE HORSEPOWER: 2874.4

TOTAL SYSTEM HORSEPOWER: 11243.3

STEAM TURBINE SHARE OF THE LOAD: 25.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.394 GT AT SYSTEM HP: 0.479

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4433.1 COGAS: 4433.1 GT AT SYSTEM HP: 5382.0

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.351 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/22/79 16.39.47

RUN #22

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE PACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4 (HEATING LENGTH= 3.4 FT.)
BOILING SECTION: 6 (BOILING LENGTH= 3.5 FT.)
SUPERHEATING SECTION: 2

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	499.2	405.5	200.0	427.7	23652.1
BOILING	744.9	499.2	427.7	444.6	
SUPERHEATING	848.4	744.9	444.6	635.0	231167.1

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38942.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.4 IN H2O

PINCH POINT: 71.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16068.7

STEAM TURBINE HORSEPOWER: 4804.9

TOTAL SYSTEM HORSEPOWER: 20873.6

STEAM TURBINE SHARE OF THE LOAD: 23.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.436 COGAS: 0.335 GT AT SYSTEM HP: 0.396

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6999.8 COGAS: 6999.8 GT AT SYSTEM HP: 8270.7

THERMAL EFFICIENCY:
GT ONLY: 0.317 COGAS: 0.412 GT AT SYSTEM HP: 0.345

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #36(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 5 (HEATING LENGTH= 4.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 1.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	527.3	465.0	200.0	498.9	43C5.7
BOILING	648.2	527.3	498.9	518.3	
SUPERHEATING	688.0	648.2	518.3	662.5	33219.9

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 7769.6 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.5 IN H2O

PINCH POINT: 28.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.6

STEAM TURBINE HORSEPOWER: 1043.8

TOTAL SYSTEM HORSEPOWER: 2705.4

STEAM TURBINE SHARE OF THE LOAD: 38.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.653 GT AT SYSTEM HP: 0.877

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.3 COGAS: 1766.3 GT AT SYSTEM HP: 2372.3

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.212 GT AT SYSTEM HP: 0.156

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #35

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 4 (HEATING LENGTH= 1.6 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	543.7	459.9	200.0	513.3	11569.7
BOILING	643.5	543.7	513.3	518.3	
SUPERHEATING	741.8	643.5	518.3	645.0	91410.0

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 20426.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.7 IN H2O

PINCH POINT: 30.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8391.1

STEAM TURBINE HORSEPOWER: 2706.8

TOTAL SYSTEM HORSEPOWER: 11098.0

STEAM TURBINE SHARE OF THE LOAD: 24.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.400 GT AT SYSTEM HP: 0.481

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4435.4 COGAS: 4435.4 GT AT SYSTEM HP: 5334.1

THERMAL EFFICIENCY:
GT ONLY: 0.262 COGAS: 0.346 GT AT SYSTEM HP: 0.28E

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #34(o)

08/25/75 15.07.21

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 5 (HEATING LENGTH= 5.0 FT.)
SUPERHEATING SECTION: 1 (BOILING LENGTH= 1.7 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	552.1	441.0	200.0	487.7	20064.0
BOILING	778.1	552.1	487.7	518.3	
SUPERHEATING	847.1	778.1	518.3	633.8	154754.6

STEAM PRESSURE: 800.0 PSIA (SATURATION TEMPERATURE= 518.3 F)

STEAM FLOW RATE: 36836.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.5 IN H2O

PINCH POINT: 64.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16132.9

STEAM TURBINE HORSEPOWER: 4838.2

TOTAL SYSTEM HORSEPOWER: 20971.1

STEAM TURBINE SHARE OF THE LOAD: 23.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.434 COGAS: 0.334 GT AT SYSTEM HP: 0.394

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7008.6 COGAS: 7008.6 GT AT SYSTEM HP: 8267.6

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.414 GT AT SYSTEM HP: 0.351

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.00 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/25/79 15.51.44

RUN #42(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 3.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 14 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 0.8 FT.)
SUPERHEATING SECTION: 4 (BOILING LENGTH= 4.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	497.9	430.5	200.0	485.0	4700.4
BOILING	606.8	497.9	485.0	486.3	
SUPERHEATING	688.8	606.8	486.3	670.0	40168.4

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8814.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

PINCH POINT: 14.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.0

STEAM TURBINE HORSEPOWER: 1164.2

TOTAL SYSTEM HORSEPOWER: 2825.2

STEAM TURBINE SHARE OF THE LOAD: 41.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.625 GT AT SYSTEM HP: 0.860

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.1 COGAS: 1766.1 GT AT SYSTEM HP: 2429.7

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.221 GT AT SYSTEM HP: 0.161

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

06/25/79 15.06.16

RUN #41(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 3.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 14 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 7 (HEATING LENGTH= 3.7 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 1.9 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	506.1	428.0	200.0	475.6	11462.9
BOILING	680.4	506.1	475.6	486.3	
SUPERHEATING	741.2	680.4	486.3	687.5	96788.1

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21620.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.4 IN H2O

PINCH POINT: 30.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8379.2

STEAM TURBINE HORSEPOWER: 2918.0

TOTAL SYSTEM HORSEPOWER: 11297.2

STEAM TURBINE SHARE OF THE LOAD: 25.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.393 GT AT SYSTEM HP: 0.478

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4434.2 COGAS: 4434.2 GT AT SYSTEM HP: 5399.8

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.352 GT AT SYSTEM HP: 0.285

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #40

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 3.4 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 14 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 7 (HEATING LENGTH= 5.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	513.4	402.3	200.0	467.5	20576.3
BOILING	737.5	513.4	467.5	486.3	
SUPERHEATING	850.6	737.5	486.3	650.0	179758.6

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 39693.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.5 IN H2O

PINCH POINT: 45.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16101.5

STEAM TURBINE HORSEPOWER: 5167.7

TOTAL SYSTEM HORSEPOWER: 21269.2

STEAM TURBINE SHARE OF THE LOAD: 24.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.329 GT AT SYSTEM HP: 0.387

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7004.3 COGAS: 7004.3 GT AT SYSTEM HP: 8237.9

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.420 GT AT SYSTEM HP: 0.357

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #42(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 4.1 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 1.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	498.7	435.0	200.0	474.4	4552.9
BOILING	639.4	498.7	474.4	486.3	
SUPERHEATING	687.9	639.4	486.3	661.3	38478.7

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8685.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

PINCH POINT: 24.3 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.3

STEAM TURBINE HORSEPOWER: 1140.0

TOTAL SYSTEM HORSEPOWER: 2801.3

STEAM TURBINE SHARE OF THE LOAD: 40.7 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.630 GT AT SYSTEM HP: 0.863

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.2 COGAS: 1766.2 GT AT SYSTEM HP: 2418.4

THERMAL EFFICIENCY:
GT ONLY: 0.130 COGAS: 0.219 GT AT SYSTEM HP: 0.160

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #41

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 0.9 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	516.0	435.0	200.0	484.4	11664.0
BOILING	683.2	516.0	484.4	486.3	
SUPERHEATING	741.7	683.2	486.3	641.3	97271.8

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21894.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.0 IN H2O

PINCH POINT: 31.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8385.5

STEAM TURBINE HORSEPOWER: 2832.3

TOTAL SYSTEM HORSEPOWER: 11217.8

STEAM TURBINE SHARE OF THE LOAD: 25.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.527 COGAS: 0.395 GT AT SYSTEM HP: 0.479

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4434.8 COGAS: 4434.8 GT AT SYSTEM HP: 5373.6

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.350 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #40(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 5.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	522.8	418.8	200.0	460.6	19625.8
BOILING	730.7	522.8	460.6	486.3	
SUPERHEATING	850.0	730.7	486.3	647.5	173776.7

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 38266.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.0 IN H2O

PINCH POINT: 62.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16116.8

STEAM TURBINE HORSEPOWER: 4972.8

TOTAL SYSTEM HORSEPOWER: 21089.7

STEAM TURBINE SHARE OF THE LOAD: 23.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.332 GT AT SYSTEM HP: 0.392

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7006.4 COGAS: 7006.4 GT AT SYSTEM HP: 8259.7

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.416 GT AT SYSTEM HP: 0.353

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.06 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #54(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 2
BOILING SECTION: 4 (HEATING LENGTH= 3.8 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 3.9 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	461.6	403.0	200.0	425.8	4683.4
BOILING	587.7	461.6	425.8	444.6	
SUPERHEATING	687.9	587.7	444.6	667.5	45829.2

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 9609.1 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.4 IN H2O

PINCH POINT: 35.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1661.7

STEAM TURBINE HORSEPOWER: 1212.5

TOTAL SYSTEM HORSEPOWER: 2874.2

STEAM TURBINE SHARE OF THE LOAD: 42.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.063 COGAS: 0.615 GT AT SYSTEM HP: 0.853

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1766.3 COGAS: 1766.3 GT AT SYSTEM HP: 2452.6

THERMAL EFFICIENCY:
GT ONLY: 0.133 COGAS: 0.225 GT AT SYSTEM HP: 0.162

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #53

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.3 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.1 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 4 (HEATING LENGTH= 0.3 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.7 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	481.5	405.1	200.0	444.6	11921.6
BOILING	621.7	481.5	444.6	444.6	
SUPERHEATING	739.6	621.7	444.6	630.0	115150.3

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 23698.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.6 IN H2O

PINCH POINT: 36.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8392.6

STEAM TURBINE HORSEPOWER: 2913.9

TOTAL SYSTEM HORSEPOWER: 11306.5

STEAM TURBINE SHARE OF THE LOAD: 25.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.529 COGAS: 0.392 GT AT SYSTEM HP: 0.478

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4435.6 COGAS: 4435.6 GT AT SYSTEM HP: 5402.8

THERMAL EFFICIENCY:
GT ONLY: 0.262 COGAS: 0.352 GT AT SYSTEM HP: 0.285

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

RUN #52(o)

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.0 FT.
HEIGHT: 1.5 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.0 IN.
INSIDE TUBE DIAMETER: 0.9 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 11.88 FINS/IN.
FIN HEIGHT: 0.5 IN.
FIN THICKNESS: 0.024 IN.

TRANSVERSE TUBE SPACING: 2.25 IN.

LONGITUDINAL TUBE SPACING: 1.95 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 80.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4081.2 SQ.FT.

INSIDE AREA/PASS: 234.4 SQ. FT.

FRONTAL AREA: 179.8 SQ. FT.

NUMBER OF PASSES: 9 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 4 (HEATING LENGTH= 0.9 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.9 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	501.4	405.0	200.0	439.0	18992.1
BOILING	706.8	501.4	439.0	444.6	
SUPERHEATING	848.8	706.8	444.6	690.0	180690.5

STEAM PRESSURE: 400.0 PSIA (SATURATION TEMPERATURE= 444.6 F)

STEAM FLOW RATE: 38086.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.5 IN H2O

PINCH POINT: 62.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16135.3

STEAM TURBINE HORSEPOWER: 4880.7

TOTAL SYSTEM HORSEPOWER: 21016.0

STEAM TURBINE SHARE OF THE LOAD: 23.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.434 COGAS: 0.334 GT AT SYSTEM HP: 0.393

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7008.9 COGAS: 7008.9 GT AT SYSTEM HP: 8265.1

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.415 GT AT SYSTEM HP: 0.352

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

```
     BRAKE HORSEPOWER:   1684.0,  APPROXIMATE CORRESPONDING SHIP SPEED:   9.0  KTS
     EXHAUST GAS TEMPERATURE:   689.0  F
     EXHAUST GAS FLOW RATE:  159731.0  LBM/HR  ( 44.4  LBM/SEC)
```

HEAT EXCHANGER GEOMETRY

```
     OVERALL DIMENSIONS:
          LENGTH:  12.0  FT.
          WIDTH:   15.2  FT.
          HEIGHT:   2.9  FT.

     HEAT TRANSFER SURFACE
          OUTSIDE TUBE DIAMETER:   1.5  IN.
          INSIDE TUBE DIAMETER:   1.4  IN.
          TUBE/FIN ARRANGEMENT:
               FIN TYPE:  SEGMENTED
               FIN SPACING:   7.92  FINS/IN.
               FIN HEIGHT:  0.8  IN.
               FIN THICKNESS:  0.036  IN.

     TRANSVERSE TUBE SPACING:   3.38  IN.

     LONGITUDINAL TUBE SPACING:   2.92  IN.

     NUMBER OF ROWS PER PASS:    1.

     NUMBER OF TUBES PER  ROW:   54.

     TUBE LENGTH  12.  FT.

     OUTSIDE AREA/PASS:   4132.2  SQ.FT.

     INSIDE AREA/PASS:   237.3  SQ. FT.

     FRONTAL AREA:  181.9  SQ. FT.

     NUMBER OF PASSES:  12  (TOTAL)
          HEATING SECTION:         3
          BOILING SECTION:         6    (HEATING LENGTH=  4.1 FT.)
          SUPERHEATING SECTION:    3    (BOILING LENGTH=  1.7 FT.)
```

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	498.7	435.0	200.0	474.4	4552.9
BOILING	639.4	498.7	474.4	486.3	
SUPERHEATING	688.1	639.4	486.3	662.5	38336.8

```
     STEAM PRESSURE:  600.0   PSIA   (SATURATION TEMPERATURE=  486.3  F)

     STEAM FLOW RATE:   8685.4  LBM/HR.

     GAS-SIDE PRESSURE DROP:   0.6   IN H2O

     PINCH POINT:   24.3  F
```

SYSTEM PERFORMANCE

```
     GT HORSEPOWER(REVISED):   1661.3

     STEAM TURBINE HORSEPOWER:   1141.0

     TOTAL SYSTEM HORSEPOWER:   2802.3

     STEAM TURBINE SHARE OF THE LOAD:  40.7  PERCENT

     SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
          GT ONLY:  1.063    COGAS:  0.630    GT AT SYSTEM HP:  0.863

     FUEL CONSUMPTION (LBM-FUEL/HR.):
          GT ONLY:  1766.2   COGAS:  1766.2   GT AT SYSTEM HP:  2418.9

     THERMAL EFFICIENCY:
          GT ONLY:  0.133    COGAS:  0.219    GT AT SYSTEM HP:  0.160

     ASSUMED SYSTEM CHARACTERISTICS:

          CONDENSER PRESSURE:  4.08   IN. HG
          STEAM TURBINE EFFICIENCY:  0.85
          FW HEATER PRESSURE:    15.0  PSIA
          LHV OF FUEL:  18400  BTU/LBM
```

08/16/79 12.34.30

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1895.0, APPROXIMATE CORRESPONDING SHIP SPEED: 10.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 167075.0 LBM/HR (46.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 4.4 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 2.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	498.5	435.0	200.0	473.1	4757.0
BOILING	631.5	498.5	473.1	486.3	
SUPERHEATING	687.6	631.5	486.3	660.0	40389.8

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 9084.8 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.6 IN H2O

PINCH POINT: 25.3 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1869.2

STEAM TURBINE HORSEPOWER: 1191.3

TOTAL SYSTEM HORSEPOWER: 3060.6

STEAM TURBINE SHARE OF THE LOAD: 38.9 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.022 COGAS: 0.624 GT AT SYSTEM HP: 0.829

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1910.7 COGAS: 1910.7 GT AT SYSTEM HP: 2536.6

THERMAL EFFICIENCY:
GT ONLY: 0.135 COGAS: 0.222 GT AT SYSTEM HP: 0.167

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/16/79 12.50.27

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 3158.0, APPROXIMATE CORRESPONDING SHIP SPEED: 12.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 223990.0 LBM/HR (62.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.36 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 4.3 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 3.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	501.8	439.5	200.0	471.9	6282.8
BOILING	627.0	501.8	471.9	486.3	
SUPERHEATING	687.9	627.0	486.3	652.5	54035.3

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 12028.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.0 IN H2O

PINCH POINT: 29.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 3112.3

STEAM TURBINE HORSEPOWER: 1568.9

TOTAL SYSTEM HORSEPOWER: 4681.2

STEAM TURBINE SHARE OF THE LOAD: 33.5 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.828 COGAS: 0.551 GT AT SYSTEM HP: 0.672

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 2577.1 COGAS: 2577.1 GT AT SYSTEM HP: 3143.8

THERMAL EFFICIENCY:
GT ONLY: 0.167 COGAS: 0.251 GT AT SYSTEM HP: 0.206

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/16/79 15.47.07

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 4316.0, APPROXIMATE CORRESPONDING SHIP SPEED: 13.0 KTS
EXHAUST GAS TEMPERATURE: 699.0 F
EXHAUST GAS FLOW RATE: 262546.0 LBM/HR (72.9 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 15.2 FT.
- HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: 1.5 IN.
- INSIDE TUBE DIAMETER: 1.4 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 7.92 FINS/IN.
  - FIN HEIGHT: 0.8 IN.
  - FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
- HEATING SECTION: 3
- BOILING SECTION: 6 (HEATING LENGTH= 5.1 FT.)
- SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	502.7	438.5	200.0	467.5	7675.4
BOILING	620.6	502.7	467.5	486.3	
SUPERHEATING	699.3	620.6	486.3	647.5	67796.6

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 14806.4 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.3 IN H2O

PINCH POINT: 35.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 4250.8

STEAM TURBINE HORSEPOWER: 1924.2

TOTAL SYSTEM HORSEPOWER: 6175.0

STEAM TURBINE SHARE OF THE LOAD: 31.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.710 COGAS: 0.489 GT AT SYSTEM HP: 0.589

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 3018.3 COGAS: 3018.3 GT AT SYSTEM HP: 3639.4

THERMAL EFFICIENCY:
GT ONLY: 0.195 COGAS: 0.283 GT AT SYSTEM HP: 0.235

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 5474.0, APPROXIMATE CORRESPONDING SHIP SPEED: 14.0 KTS
EXHAUST GAS TEMPERATURE: 709.0 F
EXHAUST GAS FLOW RATE: 279070.0 LBM/HR (77.5 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 5.2 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.6 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	504.3	438.0	200.0	465.6	8467.9
BOILING	630.1	504.3	465.6	486.3	
SUPERHEATING	710.3	630.1	486.3	655.0	74819.9

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 16381.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.5 IN H2O

PINCH POINT: 36.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 5389.5

STEAM TURBINE HORSEPOWER: 2140.5

TOTAL SYSTEM HORSEPOWER: 7530.0

STEAM TURBINE SHARE OF THE LOAD: 28.4 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.632 COGAS: 0.452 GT AT SYSTEM HP: 0.545

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 3404.5 COGAS: 3404.5 GT AT SYSTEM HP: 4100.7

THERMAL EFFICIENCY:
GT ONLY: 0.219 COGAS: 0.306 GT AT SYSTEM HP: 0.254

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

```
BRAKE HORSEPOWER:  6947.0,  APPROXIMATE CORRESPONDING SHIP SPEED:  15.0  KTS
EXHAUST GAS TEMPERATURE:  733.0  F
EXHAUST GAS FLOW RATE:  312118.0  LBM/HR  ( 86.7  LBM/SEC)
```

HEAT EXCHANGER GEOMETRY

```
OVERALL DIMENSIONS:                              NUMBER OF ROWS PER PASS:   1.
     LENGTH:  12.0  FT.
     WIDTH:   15.2  FT.                          NUMBER OF TUBES PER ROW:   54.
     HEIGHT:   2.5  FT.
                                                 TUBE LENGTH  12.  FT.
HEAT TRANSFER SURFACE
  OUTSIDE TUBE DIAMETER:   1.5  IN.              OUTSIDE AREA/PASS:   4132.2  SQ.FT.
  INSIDE TUBE DIAMETER:   1.4  IN.
  TUBE/FIN ARRANGEMENT:                          INSIDE AREA/PASS:   237.3  SQ. FT.
     FIN TYPE:  SEGMENTED
     FIN SPACING:   7.92  FINS/IN.               FRONTAL AREA:  181.9  SQ. FT.
     FIN HEIGHT:  0.8  IN.
     FIN THICKNESS:  0.036  IN.                  NUMBER OF PASSES:  12  (TOTAL)
                                                    HEATING SECTION:       4
TRANSVERSE TUBE SPACING:   3.38  IN.                BOILING SECTION:       6   (HEATING LENGTH=  0.5 FT.)
                                                    SUPERHEATING SECTION:  2   (BOILING LENGTH=  2.4 FT.)
LONGITUDINAL TUBE SPACING:   2.92  IN.
```

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	513.8	435.0	200.0	485.0	10757.3
BOILING	673.4	513.8	485.0	486.3	
SUPERHEATING	732.1	673.4	486.3	638.8	89617.3

```
STEAM PRESSURE:  600.0  PSIA  (SATURATION TEMPERATURE=  486.3  F)

STEAM FLOW RATE:  20172.7  LBM/HR.

GAS-SIDE PRESSURE DROP:   1.8  IN H2O

PINCH POINT:   28.8  F
```

SYSTEM PERFORMANCE

```
GT HORSEPOWER(REVISED):   6835.2                 ASSUMED SYSTEM CHARACTERISTICS:

STEAM TURBINE HORSEPOWER:   2604.9                  CONDENSER PRESSURE:  4.08  IN. HG
                                                    STEAM TURBINE EFFICIENCY:  0.85
TOTAL SYSTEM HORSEPOWER:   9440.0                   FW HEATER PRESSURE:   15.0  PSIA
                                                    LHV OF FUEL:  18400  BTU/LBM
STEAM TURBINE SHARE OF THE LOAD:  27.6  PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
   GT ONLY:  0.569     COGAS:  0.412     GT AT SYSTEM HP:  0.505

FUEL CONSUMPTION (LBM-FUEL/HR.):
   GT ONLY:  3892.0    COGAS:  3892.0    GT AT SYSTEM HP:  4769.3

THERMAL EFFICIENCY:
   GT ONLY:  0.243     COGAS:  0.335     GT AT SYSTEM HP:  0.274
```

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 8526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.36 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 0.6 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	516.0	435.0	200.0	484.4	11664.0
BOILING	683.2	516.0	484.4	486.3	
SUPERHEATING	741.7	683.2	486.3	641.3	97271.8

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21894.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.0 IN H2O

PINCH POINT: 31.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8385.5

STEAM TURBINE HORSEPOWER: 2832.3

TOTAL SYSTEM HORSEPOWER: 11217.8

STEAM TURBINE SHARE OF THE LOAD: 25.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.520 COGAS: 0.395 GT AT SYSTEM HP: 0.475

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4434.8 COGAS: 4434.8 GT AT SYSTEM HP: 5373.6

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.350 GT AT SYSTEM HP: 0.285

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 10421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 17.0 KTS
EXHAUST GAS TEMPERATURE: 786.0 F
EXHAUST GAS FLOW RATE: 350673.0 LBM/HR (97.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4 (HEATING LENGTH= 3.5 FT.)
BOILING SECTION: 6 (BOILING LENGTH= 3.6 FT.)
SUPERHEATING SECTION: 2

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	516.6	425.0	200.0	473.1	14414.3
BOILING	696.5	516.6	473.1	486.3	
SUPERHEATING	786.0	696.5	486.3	642.5	123750.3

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 27527.7 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.3 IN H2O

PINCH POINT: 43.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 10243.8

STEAM TURBINE HORSEPOWER: 3564.3

TOTAL SYSTEM HORSEPOWER: 13808.1

STEAM TURBINE SHARE OF THE LOAD: 25.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.497 COGAS: 0.369 GT AT SYSTEM HP: 0.449

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 5088.5 COGAS: 5088.5 GT AT SYSTEM HP: 6195.5

THERMAL EFFICIENCY:
GT ONLY: 0.278 COGAS: 0.375 GT AT SYSTEM HP: 0.308

ASSUMED SYSTEM CHARACTERISTICS:
CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 12105.0, APPROXIMATE CORRESPONDING SHIP SPEED: 18.0 KTS
EXHAUST GAS TEMPERATURE: 809.0 F
EXHAUST GAS FLOW RATE: 381885.0 LBM/HR (106.1 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 4.4 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.2 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	519.1	423.0	200.0	468.1	16677.8
BOILING	705.8	519.1	468.1	486.3	
SUPERHEATING	808.4	705.8	486.3	640.0	145423.7

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 32094.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.6 IN H2O

PINCH POINT: 51.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 11889.6

STEAM TURBINE HORSEPOWER: 4148.1

TOTAL SYSTEM HORSEPOWER: 16037.7

STEAM TURBINE SHARE OF THE LOAD: 25.9 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.474 COGAS: 0.352 GT AT SYSTEM HP: 0.431

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 5640.5 COGAS: 5640.5 GT AT SYSTEM HP: 6916.9

THERMAL EFFICIENCY:
GT ONLY: 0.251 COGAS: 0.393 GT AT SYSTEM HP: 0.321

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 13790.0, APPROXIMATE CORRESPONDING SHIP SPEED: 15.0 KTS
EXHAUST GAS TEMPERATURE: 820.0 F
EXHAUST GAS FLOW RATE: 387393.0 LBM/HR (107.6 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 6 (HEATING LENGTH= 4.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	519.9	421.5	200.0	466.3	17400.5
BOILING	712.1	519.9	466.3	486.3	
SUPERHEATING	819.2	712.1	486.3	640.0	152658.3

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 33631.7 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.7 IN H2O

PINCH POINT: 53.7 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 13542.5

STEAM TURBINE HORSEPOWER: 4346.7

TOTAL SYSTEM HORSEPOWER: 17889.2

STEAM TURBINE SHARE OF THE LOAD: 24.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.455 COGAS: 0.345 GT AT SYSTEM HP: 0.423

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6165.9 COGAS: 6165.9 GT AT SYSTEM HP: 7566.7

THERMAL EFFICIENCY:
GT ONLY: 0.304 COGAS: 0.401 GT AT SYSTEM HP: 0.327

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 15.2 FT.
- HEIGHT: 2.9 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: 1.5 IN.
- INSIDE TUBE DIAMETER: 1.4 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 7.92 FINS/IN.
  - FIN HEIGHT: 0.8 IN.
  - FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
- HEATING SECTION: 4 (HEATING LENGTH= 5.5 FT.)
- BOILING SECTION: 6 (BOILING LENGTH= 4.5 FT.)
- SUPERHEATING SECTION: 2

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	522.8	418.8	200.0	460.6	19625.8
BOILING	730.7	522.8	460.6	486.3	
SUPERHEATING	849.8	730.7	486.3	646.3	173910.7

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 38266.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.0 IN H2O

PINCH POINT: 62.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 16116.8

STEAM TURBINE HORSEPOWER: 4968.3

TOTAL SYSTEM HORSEPOWER: 21085.1

STEAM TURBINE SHARE OF THE LOAD: 23.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.435 COGAS: 0.332 GT AT SYSTEM HP: 0.392

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 7306.4 COGAS: 7006.4 GT AT SYSTEM HP: 8259.5

THERMAL EFFICIENCY:
GT ONLY: 0.318 COGAS: 0.416 GT AT SYSTEM HP: 0.353

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 20000.0, APPROXIMATE CORRESPONDING SHIP SPEED: 21.5 KTS
EXHAUST GAS TEMPERATURE: 897.0 F
EXHAUST GAS FLOW RATE: 440630.0 LBM/HR (122.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 15.2 FT.
HEIGHT: 2.0 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.34 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 54.

TUBE LENGTH: 12. FT.

OUTSIDE AREA/PASS: 4132.2 SQ.FT.

INSIDE AREA/PASS: 237.3 SQ. FT.

FRONTAL AREA: 181.9 SQ. FT.

NUMBER OF PASSES: 12 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 5 (HEATING LENGTH= 0.0 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.0 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	549.3	418.0	200.0	486.3	24552.9
BOILING	750.8	545.8	486.3	486.3	
SUPERHEATING	895.0	756.8	486.3	647.5	210054.9

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 45949.3 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.5 IN H2O

PINCH POINT: 59.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 19610.5

STEAM TURBINE HORSEPOWER: 5971.3

TOTAL SYSTEM HORSEPOWER: 25581.8

STEAM TURBINE SHARE OF THE LOAD: 23.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.417 COGAS: 0.320 GT AT SYSTEM HP: 0.013

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 8183.2 COGAS: 8183.2 GT AT SYSTEM HP: 333.4

THERMAL EFFICIENCY:
GT ONLY: 0.331 COGAS: 0.432 GT AT SYSTEM HP: *****

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/21/79 15.48.33

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1684.0, APPROXIMATE CORRESPONDING SHIP SPEED: 9.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 159731.0 LBM/HR (44.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.1 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 6 (HEATING LENGTH= 4.8 FT.)
SUPERHEATING SECTION: 4 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	498.9	436.5	200.0	471.3	5643.0
BOILING	611.5	498.9	471.3	486.3	
SUPERHEATING	688.6	611.5	486.3	667.5	49203.8

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 8612.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 0.9 IN H2O

PINCH POINT: 27.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1660.1

STEAM TURBINE HORSEPOWER: 1135.5

TOTAL SYSTEM HORSEPOWER: 2795.6

STEAM TURBINE SHARE OF THE LOAD: 40.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.064 COGAS: 0.632 GT AT SYSTEM HP: 0.864

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1765.9 COGAS: 1765.9 GT AT SYSTEM HP: 2415.7

THERMAL EFFICIENCY:
GT ONLY: 0.133 COGAS: 0.219 GT AT SYSTEM HP: 0.160

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 1895.0, APPROXIMATE CORRESPONDING SHIP SPEED: 10.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 167075.0 LBM/HR (46.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 12.1 FT.
- HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: 1.5 IN.
- INSIDE TUBE DIAMETER: 1.4 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 7.92 FINS/IN.
  - FIN HEIGHT: 0.8 IN.
  - FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
- HEATING SECTION: 3
- BOILING SECTION: 6 (HEATING LENGTH= 5.0 FT.)
- SUPERHEATING SECTION: 4 (BOILING LENGTH= 4.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	499.0	436.5	200.0	470.0	5922.7
BOILING	608.6	499.0	470.0	486.3	
SUPERHEATING	689.8	608.6	486.3	667.5	52032.4

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 9055.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.0 IN H2O

PINCH POINT: 29.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 1867.8

STEAM TURBINE HORSEPOWER: 1193.8

TOTAL SYSTEM HORSEPOWER: 3061.7

STEAM TURBINE SHARE OF THE LOAD: 39.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 1.023 COGAS: 0.624 GT AT SYSTEM HP: 0.829

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 1910.4 COGAS: 1910.4 GT AT SYSTEM HP: 2537.0

THERMAL EFFICIENCY:
GT ONLY: 0.135 COGAS: 0.222 GT AT SYSTEM HP: 0.167

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 2105.0, APPROXIMATE CORRESPONDING SHIP SPEED: 11.0 KTS
EXHAUST GAS TEMPERATURE: 689.0 F
EXHAUST GAS FLOW RATE: 170747.0 LBM/HR (47.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 12.1 FT.
- HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: 1.5 IN.
- INSIDE TUBE DIAMETER: 1.4 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 7.92 FINS/IN.
  - FIN HEIGHT: 0.8 IN.
  - FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
- HEATING SECTION: 4
- BOILING SECTION: 6 (HEATING LENGTH= 0.3 FT.)
- SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.2 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	502.0	435.0	200.0	486.3	6262.5
BOILING	615.7	502.0	486.3	486.3	
SUPERHEATING	687.5	615.7	486.3	645.0	53330.6

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 9332.5 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.0 IN H2O

PINCH POINT: 15.8 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 2074.7

STEAM TURBINE HORSEPOWER: 1210.6

TOTAL SYSTEM HORSEPOWER: 3285.3

STEAM TURBINE SHARE OF THE LOAD: 36.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.985 COGAS: 0.622 GT AT SYSTEM HP: 0.801

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 2042.8 COGAS: 2042.8 GT AT SYSTEM HP: 2632.4

THERMAL EFFICIENCY:
GT ONLY: 0.140 COGAS: 0.222 GT AT SYSTEM HP: 0.173

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

AD-A078 154 NAVAL POSTGRADUATE SCHOOL MONTEREY CA F/G 13/10
WASTE HEAT RECOVERY UNIT DESIGN FOR GAS TURBINE PROPULSION SYST--ETC(U)
SEP 79 R M COMBS

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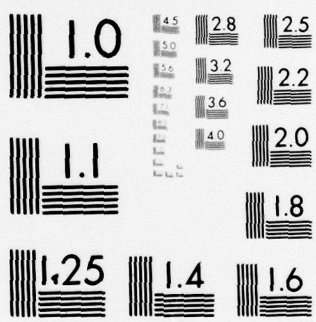

MICROCOPY RESOLUTION TEST CHART

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 3158.0, APPROXIMATE CORRESPONDING SHIP SPEED: 12.0 KTS
EXHAUST GAS TEMPERATURE: 683.0 F
EXHAUST GAS FLOW RATE: 223990.0 LBM/HR (62.2 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 7 (HEATING LENGTH= 5.4 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 1.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	500.9	440.0	200.0	466.9	7809.7
BOILING	650.0	500.9	466.9	486.3	
SUPERHEATING	688.9	650.0	486.3	658.8	66615.3

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 12005.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 1.7 IN H2O

PINCH POINT: 34.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 3108.0

STEAM TURBINE HORSEPOWER: 1572.9

TOTAL SYSTEM HORSEPOWER: 4680.8

STEAM TURBINE SHARE OF THE LOAD: 33.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.827 COGAS: 0.551 GT AT SYSTEM HP: 0.672

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 2576.9 COGAS: 2576.9 GT AT SYSTEM HP: 3143.6

THERMAL EFFICIENCY:
GT ONLY: 0.167 COGAS: 0.251 GT AT SYSTEM HP: 0.206

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/27/75 14.18.13

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 4316.0, APPROXIMATE CORRESPONDING SHIP SPEED: 13.0 KTS
EXHAUST GAS TEMPERATURE: 699.0 F
EXHAUST GAS FLOW RATE: 262546.0 LBM/HR (72.9 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 3
BOILING SECTION: 7 (HEATING LENGTH= 5.2 FT.)
SUPERHEATING SECTION: 3 (BOILING LENGTH= 0.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	505.0	443.0	200.0	465.6	9350.0
BOILING	667.1	505.0	465.6	486.3	
SUPERHEATING	698.7	667.1	486.3	667.5	79304.0

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 14403.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.3 IN H2O

PINCH POINT: 39.3 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 4242.5

STEAM TURBINE HORSEPOWER: 1899.0

TOTAL SYSTEM HORSEPOWER: 6141.5

STEAM TURBINE SHARE OF THE LOAD: 30.9 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.711 COGAS: 0.491 GT AT SYSTEM HP: 0.591

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 3018.1 COGAS: 3018.1 GT AT SYSTEM HP: 3628.2

THERMAL EFFICIENCY:
GT ONLY: 0.194 COGAS: 0.281 GT AT SYSTEM HP: 0.234

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 5474.0, APPROXIMATE CORRESPONDING SHIP SPEED: 14.0 KTS
EXHAUST GAS TEMPERATURE: 709.0 F
EXHAUST GAS FLOW RATE: 279070.0 LBM/HR (77.5 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 12.1 FT.
- HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: 1.5 IN.
- INSIDE TUBE DIAMETER: 1.4 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 7.92 FINS/IN.
  - FIN HEIGHT: 0.8 IN.
  - FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
- HEATING SECTION: 4
- BOILING SECTION: 6 (HEATING LENGTH= 0.0 FT.)
- SUPERHEATING SECTION: 3 (BOILING LENGTH= 4.3 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	512.1	441.5	200.0	486.3	10796.5
BOILING	636.0	512.1	486.3	486.3	
SUPERHEATING	708.4	636.0	486.3	651.3	92072.9

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 16089.2 LBM/HR.

GAS-SIDE PRESSURE DROP: 2.4 IN H2O

PINCH POINT: 25.9 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 5378.9

STEAM TURBINE HORSEPOWER: 2096.5

TOTAL SYSTEM HORSEPOWER: 7475.4

STEAM TURBINE SHARE OF THE LOAD: 28.0 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.633 COGAS: 0.455 GT AT SYSTEM HP: 0.546

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 3404.2 COGAS: 3404.2 GT AT SYSTEM HP: 4081.8

THERMAL EFFICIENCY:
GT ONLY: 0.219 COGAS: 0.304 GT AT SYSTEM HP: 0.253

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6947.0, APPROXIMATE CORRESPONDING SHIP SPEED: 15.0 KTS
EXHAUST GAS TEMPERATURE: 733.0 F
EXHAUST GAS FLOW RATE: 312118.0 LBM/HR (86.7 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.39 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 7 (HEATING LENGTH= 2.3 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 0.4 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	512.9	436.5	200.0	479.4	13259.6
BOILING	698.4	512.9	479.4	496.3	
SUPERHEATING	732.5	698.4	486.3	647.5	109833.1

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 19968.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.0 IN H2O

PINCH POINT: 33.5 F

SYSTEM PERFORMANCE

GT HORSEPOWER (REVISED): 6818.4

STEAM TURBINE HORSEPOWER: 2594.9

TOTAL SYSTEM HORSEPOWER: 9413.3

STEAM TURBINE SHARE OF THE LOAD: 27.6 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.571 COGAS: 0.413 GT AT SYSTEM HP: 0.506

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 3890.8 COGAS: 3890.8 GT AT SYSTEM HP: 4760.0

THERMAL EFFICIENCY:
GT ONLY: 0.242 COGAS: 0.335 GT AT SYSTEM HP: 0.273

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 6526.0, APPROXIMATE CORRESPONDING SHIP SPEED: 16.0 KTS
EXHAUST GAS TEMPERATURE: 742.0 F
EXHAUST GAS FLOW RATE: 328641.0 LBM/HR (91.3 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.39 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 7 (HEATING LENGTH= 3.5 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 2.1 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	512.1	433.5	200.0	475.0	14512.9
BOILING	687.2	512.1	475.0	486.3	
SUPERHEATING	741.2	687.2	486.3	637.5	122600.3

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 21999.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.3 IN H2O

PINCH POINT: 37.1 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 8363.3

STEAM TURBINE HORSEPOWER: 2838.1

TOTAL SYSTEM HORSEPOWER: 11201.3

STEAM TURBINE SHARE OF THE LOAD: 25.3 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.530 COGAS: 0.396 GT AT SYSTEM HP: 0.479

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 4432.6 COGAS: 4432.6 GT AT SYSTEM HP: 5368.2

THERMAL EFFICIENCY:
GT ONLY: 0.261 COGAS: 0.349 GT AT SYSTEM HP: 0.289

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.00 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 10421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 17.0 KTS
EXHAUST GAS TEMPERATURE: 786.0 F
EXHAUST GAS FLOW RATE: 350673.0 LBM/HR (97.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3250.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.0 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 4
BOILING SECTION: 7 (HEATING LENGTH= 5.7 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	513.2	425.0	200.0	463.8	17825.6
BOILING	703.5	513.2	463.8	486.3	
SUPERHEATING	784.6	703.5	486.3	635.0	155577.3

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 27527.7 LBM/HR.

GAS-SIDE PRESSURE DROP: 3.7 IN H2O

PINCH POINT: 49.4 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 10213.1

STEAM TURBINE HORSEPOWER: 3544.8

TOTAL SYSTEM HORSEPOWER: 13757.9

STEAM TURBINE SHARE OF THE LOAD: 25.8 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.498 COGAS: 0.370 GT AT SYSTEM HP: 0.449

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 5085.2 COGAS: 5085.2 GT AT SYSTEM HP: 6179.8

THERMAL EFFICIENCY:
GT ONLY: 0.278 COGAS: 0.374 GT AT SYSTEM HP: 0.308

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

08/27/79 14.36.37

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 12135.0, APPROXIMATE CORRESPONDING SHIP SPEED: 18.0 KTS
EXHAUST GAS TEMPERATURE: 809.0 F
EXHAUST GAS FLOW RATE: 381885.0 LBM/HR (106.1 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 6 (HEATING LENGTH= 0.0 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 4.0 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	528.5	426.2	200.0	486.3	21363.3
BOILING	715.6	528.5	486.3	486.3	
SUPERHEATING	807.1	715.6	486.3	632.5	181258.3

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 31836.1 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.3 IN H2O

PINCH POINT: 42.2 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 11848.5

STEAM TURBINE HORSEPOWER: 4092.1

TOTAL SYSTEM HORSEPOWER: 15940.5

STEAM TURBINE SHARE OF THE LOAD: 25.7 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.475 COGAS: 0.354 GT AT SYSTEM HP: 0.432

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 5636.4 COGAS: 5636.4 GT AT SYSTEM HP: 6884.0

THERMAL EFFICIENCY:
GT ONLY: 0.291 COGAS: 0.391 GT AT SYSTEM HP: 0.320

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 13790.0, APPROXIMATE CORRESPONDING SHIP SPEED: 19.0 KTS
EXHAUST GAS TEMPERATURE: 820.0 F
EXHAUST GAS FLOW RATE: 387393.0 LBM/HR (107.6 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
LENGTH: 12.0 FT.
WIDTH: 12.1 FT.
HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
OUTSIDE TUBE DIAMETER: 1.5 IN.
INSIDE TUBE DIAMETER: 1.4 IN.
TUBE/FIN ARRANGEMENT:
FIN TYPE: SEGMENTED
FIN SPACING: 7.92 FINS/IN.
FIN HEIGHT: 0.8 IN.
FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.38 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 189.0 SQ. FT.

FRONTAL AREA: 144.8 .SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
HEATING SECTION: 5
BOILING SECTION: 6 (HEATING LENGTH= 0.3 FT.)
SUPERHEATING SECTION: 2 (BOILING LENGTH= 3.8 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	530.9	426.1	200.0	486.3	22156.0
BOILING	728.1	530.9	486.3	486.3	
SUPERHEATING	818.0	728.1	486.3	641.3	187362.6

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 33076.9 LBM/HR.

GAS-SIDE PRESSURE DROP: 4.4 IN H2O

PINCH POINT: 44.6 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 13494.2

STEAM TURBINE HORSEPOWER: 4279.0

TOTAL SYSTEM HORSEPOWER: 17773.1

STEAM TURBINE SHARE OF THE LOAD: 24.1 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.457 COGAS: 0.347 GT AT SYSTEM HP: 0.423

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: 6161.2 COGAS: 6161.2 GT AT SYSTEM HP: 7525.7

THERMAL EFFICIENCY:
GT ONLY: 0.303 COGAS: 0.399 GT AT SYSTEM HP: 0.327

ASSUMED SYSTEM CHARACTERISTICS:

CONDENSER PRESSURE: 4.08 IN. HG
STEAM TURBINE EFFICIENCY: 0.85
FW HEATER PRESSURE: 15.0 PSIA
LHV OF FUEL: 18400 BTU/LBM

WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

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BRAKE HORSEPOWER: 16421.0, APPROXIMATE CORRESPONDING SHIP SPEED: 20.0 KTS
EXHAUST GAS TEMPERATURE: 849.0 F
EXHAUST GAS FLOW RATE: 407589.0 LBM/HR (113.2 LBM/SEC)
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HEAT EXCHANGER GEOMETRY

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OVERALL DIMENSIONS:                             NUMBER OF ROWS PER PASS:   1.
     LENGTH:  12.0  FT.                         NUMBER OF TUBES PER ROW:   43.
     WIDTH:   12.1  FT.                         TUBE LENGTH  12.  FT.
     HEIGHT:   3.2  FT.                         OUTSIDE AREA/PASS:  3290.5  SQ.FT.
HEAT TRANSFER SURFACE                           INSIDE AREA/PASS:  189.0  SQ. FT.
     OUTSIDE TUBE DIAMETER:  1.5  IN.           FRONTAL AREA:  144.8  SQ. FT.
     INSIDE TUBE DIAMETER:  1.4  IN.            NUMBER OF PASSES:  13  (TOTAL)
     TUBE/FIN ARRANGEMENT:                          HEATING SECTION:        5
          FIN TYPE:  SEGMENTED                      BOILING SECTION:        6   (HEATING LENGTH=  1.5 FT.)
          FIN SPACING:  7.92  FINS/IN.              SUPERHEATING SECTION:   2   (BOILING LENGTH=  4.3 FT.)
          FIN HEIGHT:  0.8  IN.
          FIN THICKNESS:  0.036  IN.
TRANSVERSE TUBE SPACING:  3.38  IN.
LONGITUDINAL TUBE SPACING:  2.92  IN.
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HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	534.1	422.3	200.0	480.6	25259.9
BOILING	742.8	534.1	480.6	486.3	
SUPERHEATING	848.4	742.8	486.3	638.8	216614.1

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STEAM PRESSURE:  600.0  PSIA  (SATURATION TEMPERATURE=  486.3  F)
STEAM FLOW RATE:  37562.9  LBM/HR.
GAS-SIDE PRESSURE DROP:  4.9  IN H2O
PINCH POINT:  53.5  F
```

SYSTEM PERFORMANCE

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GT HORSEPOWER(REVISED):  16053.9                 ASSUMED SYSTEM CHARACTERISTICS:
STEAM TURBINE HORSEPOWER:  4902.1                    CONDENSER PRESSURE:  4.08  IN. HG
TOTAL SYSTEM HORSEPOWER:  20955.9                    STEAM TURBINE EFFICIENCY:  0.85
STEAM TURBINE SHARE OF THE LOAD:  23.4  PERCENT      FW HEATER PRESSURE:  15.0  PSIA
                                                     LHV OF FUEL:  18400  BTU/LBM
SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
    GT ONLY:  0.436    COGAS:  0.334    GT AT SYSTEM HP:  0.395
FUEL CONSUMPTION (LBM-FUEL/HR.):
    GT ONLY:  6997.8   COGAS:  6997.8   GT AT SYSTEM HP:  8268.2
THERMAL EFFICIENCY:
    GT ONLY:  0.317    COGAS:  0.414    GT AT SYSTEM HP:  0.350
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WASTE HEAT RECOVERY UNIT OFF-DESIGN RUN

GAS TURBINE

BRAKE HORSEPOWER: 20000.0, APPROXIMATE CORRESPONDING SHIP SPEED: 21.5 KTS
EXHAUST GAS TEMPERATURE: 897.0 F
EXHAUST GAS FLOW RATE: 440636.0 LBM/HR (122.4 LBM/SEC)

HEAT EXCHANGER GEOMETRY

OVERALL DIMENSIONS:
- LENGTH: 12.0 FT.
- WIDTH: 12.1 FT.
- HEIGHT: 3.2 FT.

HEAT TRANSFER SURFACE
- OUTSIDE TUBE DIAMETER: 1.5 IN.
- INSIDE TUBE DIAMETER: 1.4 IN.
- TUBE/FIN ARRANGEMENT:
  - FIN TYPE: SEGMENTED
  - FIN SPACING: 7.92 FINS/IN.
  - FIN HEIGHT: 0.9 IN.
  - FIN THICKNESS: 0.036 IN.

TRANSVERSE TUBE SPACING: 3.34 IN.

LONGITUDINAL TUBE SPACING: 2.92 IN.

NUMBER OF ROWS PER PASS: 1.

NUMBER OF TUBES PER ROW: 43.

TUBE LENGTH 12. FT.

OUTSIDE AREA/PASS: 3290.5 SQ.FT.

INSIDE AREA/PASS: 169.0 SQ. FT.

FRONTAL AREA: 144.8 SQ. FT.

NUMBER OF PASSES: 13 (TOTAL)
- HEATING SECTION: 5
- BOILING SECTION: 6 (HEATING LENGTH= 2.6 FT.)
- SUPERHEATING SECTION: 2 (BOILING LENGTH= 5.5 FT.)

HEAT EXCHANGER PERFORMANCE

SECTION	GAS TEMP. IN	GAS TEMP. OUT	FLUID TEMP. IN	FLUID TEMP. OUT	REYNOLDS NUMBER (AVG.)
HEATING	543.0	420.5	200.0	475.0	30216.1
BOILING	765.5	543.0	475.0	486.3	
SUPERHEATING	[illegible]	765.5	486.3	627.5	265866.2

STEAM PRESSURE: 600.0 PSIA (SATURATION TEMPERATURE= 486.3 F)

STEAM FLOW RATE: 45957.0 LBM/HR.

GAS-SIDE PRESSURE DROP: 5.7 IN H2O

PINCH POINT: 68.0 F

SYSTEM PERFORMANCE

GT HORSEPOWER(REVISED): 19520.6

STEAM TURBINE HORSEPOWER: 5885.3

TOTAL SYSTEM HORSEPOWER: 25405.9

STEAM TURBINE SHARE OF THE LOAD: 23.2 PERCENT

SPECIFIC FUEL CONSUMPTION (LBM-FUEL/HP-HR):
GT ONLY: 0.41[illegible] COGAS: 0.322 GT AT SYSTEM HP: 0.045

FUEL CONSUMPTION (LBM-FUEL/HR.):
GT ONLY: [illegible] COGAS: 8178.4 GT AT SYSTEM HP: 1132.8

THERMAL EFFICIENCY:
GT ONLY: 0.33[illegible] COGAS: 0.430 GT AT SYSTEM HP: 3.102

ASSUMED SYSTEM CHARACTERISTICS:
- CONDENSER PRESSURE: 4.08 IN. HG
- STEAM TURBINE EFFICIENCY: 0.85
- FW HEATER PRESSURE: 15.0 PSIA
- LHV OF FUEL: 18400 BTU/LBM

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